PB81-108805

Evaluation of Sludge Management Systems
Evaluation Checklist and Supporting Commentary

Culp/Wesner/Culp
El Dorado Hills, CA

Prepared for

Environmental Protection Agency
Washington, DC

Feb 80

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

Office of
Water Program Operations (WH-547)
Washington DC 20460

February 1980
430/9-80-001

PB81-108805

Water

EPA

Evaluation of Sludge Management Systems

Evaluation Checklist and Supporting Commentary

MCD-61

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TECHNICAL REPORT DATA
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ORT NO.

2.

3. RECIPIENT'S ACCESSION NO.
PB81 108805

LE AND SUBTITLE
Evaluation of Sludge Management Systems: Evaluation Checklist and Supporting Commentary

5. REPORT DATE
February 1980

6. PERFORMING ORGANIZATION CODE

THOR(S)

8. PERFORMING ORGANIZATION REPORT NO.
430/9-80-001

RFORMING ORGANIZATION NAME AND ADDRESS
Municipal Construction Division
Office of Water Program Operations
Washington, D.C. 20460

10. PROGRAM ELEMENT NO.
2BG 647

11. CONTRACT/GRANT NO.

ONS ING AGENCY NAME AND ADDRESS
Office of Water Programs Operation
U.S. Environmental Protection Agency
Washington, D.C. 20460

13. TYPE OF REPORT AND PERIOD COVERED
Technical Report

14. SPONSORING AGENCY CODE
700/02

UPPLEMENTARY NOTES
operation and maintenance

BSTRACT

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project

KEY WORDS AND DOCUMENT ANALYSIS

DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water pollution control	Sludge Management	

ISTRIBUTION STATEMENT

19. SECURITY CLASS (This Report)

21. NO. OF PAGES

20. SECURITY CLASS (This page)

22. PRICE

Form 2220-1 (9-73)

EPA 430/9-80-001 February 1980

EVALUATION OF SLUDGE MANAGEMENT SYSTEMS

Evaluation Checklist and Supporting Commentary

by

Gordon L. Culp
Justine A. Faisst
Daniel J. Hinrichs
Bruce R. Winsor

Culp/Wesner/Culp
Consulting Engineers
El Dorado Hills, California 95630

Contract No. 68-01-4833

Project Officers
Sherwood C. Reed
and
Robert K. Bastian
Office of Water Programs Operations
Washington, D.C. 20460

OFFICE OF WATER PROGRAMS OPERATIONS
U. S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MCD-61

ABSTRACT

This Bulletin is intended to be an aid for review of facility plans, designs, specifications, and O&M manuals which deal with sludge management systems. The document is divided into three parts: Facility Planning (Part I), Design and Specifications (Part II), and Operation and Maintenance Manuals (Part III). Each part is complete and independent of the others so it is only necessary to use those portions relevant to the project under review.

Each Part contains a checklist of pertinent factors supported by technical commentary. This technical discussion is sufficiently detailed for an understanding of the concepts but not complete enough for design. This document is not a design manual and should not be used as such. Those readers interested in design should use the Process Design Manual for Sludge Treatment and Disposal (EPA 625/1-79-011, September 1979).

At the facility planning stage the checklist can be used to assure that all feasible sludge management alternatives were properly considered. At the later stages of a project a particular concept has already been selected so the reviewer only needs to be concerned with the relevant portions of Parts II and III to insure that all critical aspects are covered.

TABLE OF CONTENTS

Page

Figures iv
Tables vi
Introduction 1
  Purpose 1
  Report Organization 1
  Use 1
  Scope 2
I. Facility Planning
  Introduction 5
  Checklist 7
    A. Project Objectives 7
    B. Characteristics of Sludge 7
    C. Existing Facilities 7
    D. Environmental Considerations 7
    E. Sludge Transport 7
    F. Land Application 8
    G. Landfill 9
    H. Combustion 10
    I. Sludge For Off-Site Use by Others 11
    J. Cost-Effectiveness Analysis 12
    K. Reliability 14
    L. Energy Analysis 14
    M. Environmental Assessment 14
    N. Implementation Program 15
  Supporting Commentary 17
    A. Project Objectives 17
    B. Characteristics of Sludge 18
    C. Existing Facilities 27
    D. Environmental Considerations 27
    E. Sludge Transport 30
    F. Land Application 36
    G. Landfill 52
    H. Combustion 59
    I. Sludge For Off-Site Use by Others 76
    J. Cost-Effectiveness Analysis 87
    K. Reliability 90
    L. Energy Analysis 93
    M. Environmental Assessment 94
    N. Implementation Program 99
II. Design and Specifications
  Introduction 103
  Checklist 105
    A. Agreement With Facilities Plan 105
    B. Sludge Transport 105
    C. Land Application 105
    D. Landfill 107
    E. Combustion 108

TABLE OF CONTENTS (Continued)

Page

F. Sludge For Off-Site Use by Others 112

Supporting Commentary

A. Agreement With Facilities Plan 115

B. Sludge Transport 115

C. Land Application 125

III. Operation and Maintenance Manual

Introduction 173

Checklist 175

A. Sludge Transport 175

B. Land Application 176

C. Landfill 177

D. Combustion 178

E. Process for Off-Site Use of Sludge By Others 179

Supporting Commentary 181

A. Sludge Transport 181

B. Land Application 186

C. Landfill 192

D. Combustion 200

E. Process for Off-Site Use of Sludge By Others 205

References 213

Bibliography 219

Appendices

A. Design of Land Application Systems For Agricultural Utilization of Sewage Sludge

B. Landfill Design

TABLES

Number		Page
1	Qualitative Comparison of Municipal Sludge With Municipal Solid Waste	18
2	Normal Quantities of Sludge Produced by Different Treatment Processes	20
3	Major Components of Stabilized Sludge	21
4	Typical Heat of Combustion of Sludge (Total Dry Solids Basis)	26
5	Pipeline Size and Flow Rates	31
6	Pipeline Sludge Pumping Characteristics	32
7	Pipeline Pumping Station Energy	32
8	Plant Nutrient Utilization by Various Crops	44
9	Suggested Total Amount of Sludge Metals Added to Agricultural Land	46
10	Typical Sludge Dewatering Performance	59
11	Sludge and Site Conditions	134
12	Landfill Design Criteria	136
13	Landfill Equipment Performance Characteristics	139
14	Multiple Hearth Furnace Loading Rates	143
15	Typical Sizes of Multiple Hearth Furnace Units	145
16	Fluidized Bed Furnace Loading Rates	151
17	Typical Composting Design Criteria	159
18	Composting Equipment	162
19	Dry Bed Loading Rates	164
20	Drying Bed Design Parameters	165
21	Drying Lagoon Design Parameters	166

FIGURES

Number		Page
1	Facility planning decision making process	3
2	Basic sludge management alternatives	4
3	Theoretical heat required to sustain combustion of sludge	60
4	Cross section of a typical multiple hearth incinerator	62
5	Cross section of a fluid bed reactor	63
6	Wet air oxidation system schematic	67
7	Impact of excess air on the amount of auxiliary fuel for sludge incineration	69
8	Potential heat recovery from incineration of sludge	72
9	Cage mill flash dryer system	81
10	Rotary kiln dryer	82
11	Static pile composting	85
12	Multiple hearth furnace area vs. design capacity	144
13	Multiple hearth air supply vs. design capacity	146
14	Multiple hearth furnace heatup and standby fuel consumption rate	147
15	Fluidized bed, bed area vs. capacity	150
16	Typical sludge dry bed construction	163
17	Typical multiple hearth furnace monitoring program	202

INTRODUCTION

INTRODUCTION

PURPOSE

Evaluation of Sludge Management Systems is intended to be an aid for review of facility plans, design and specifications, and operation and maintenance manuals which deal with sludge management systems. While this document is primarily intended for use by Environmental Protection Agency evaluators, it is anticipated that it will also be of use to public officials, planners, and engineers.

The checklists and accompanying commentary included are to be used by the evaluator to check the completeness of the work being reviewed. Data included are for illustrative purposes to aid in assessing the reasonableness of a plan or design. This document is not a design manual and should not be used as such. In the reference section of this document and throughout the text are listed many sources of additional information on the selection and design of sludge management systems which should be consulted when more information is needed. Specifically, the reader is referred to the latest edition of the EPA Process Design Manual for Sludge Treatment and Disposal.

REPORT ORGANIZATION

This report is divided into three parts: Facility Planning (Part I), Design and Specifications (Part II) and Operation and Maintenance Manuals (Part III). This reflects the normal sequence in the planning and design of municipal facilities. Each part is independent of the others. It is only necessary to use those portions relevant to the project under review.

USE

When reviewing a plan or design the evaluator should mark off items on the checklist as he comes across them. Items can be marked off for both presence and feasibility as determined by the supporting commentary and referenced material. It is not the intent of this report to limit alternatives to those discussed. If a process is not included in the checklist, it does not mean it is unacceptable. Conversely, there will be items so obviously inapplicable to the specific situation that no mention need be made in planning or design.

Under the authority of the Resource Conservation and Recovery Act (P.L. 94-580) (2) the EPA is currently preparing proposed guidelines for the utilization and disposal of sewage sludge. The requirements of these guidelines will affect the selection, design and evaluation of all the sludge management systems discussed herein. When available, these guidelines should be consulted by the evaluator, planner, designer or operation and maintenance manual author in using this publication. The information contained herein should be interpreted in light of the proposed and final guidelines.

It should be kept in mind by the evaluator that facility planning and design of a sludge management system are not conducted as straight line procedures, but instead involve several interlocking sets of decision loops, each of which affects others. Figure 1 is a flowchart which illustrates the decision-making process.

At all times during the facility planning, design and specifications preparation, and operations and maintenance manual preparation stages it must be kept in mind that the sludge management system is a part of the overall wastewater management system.

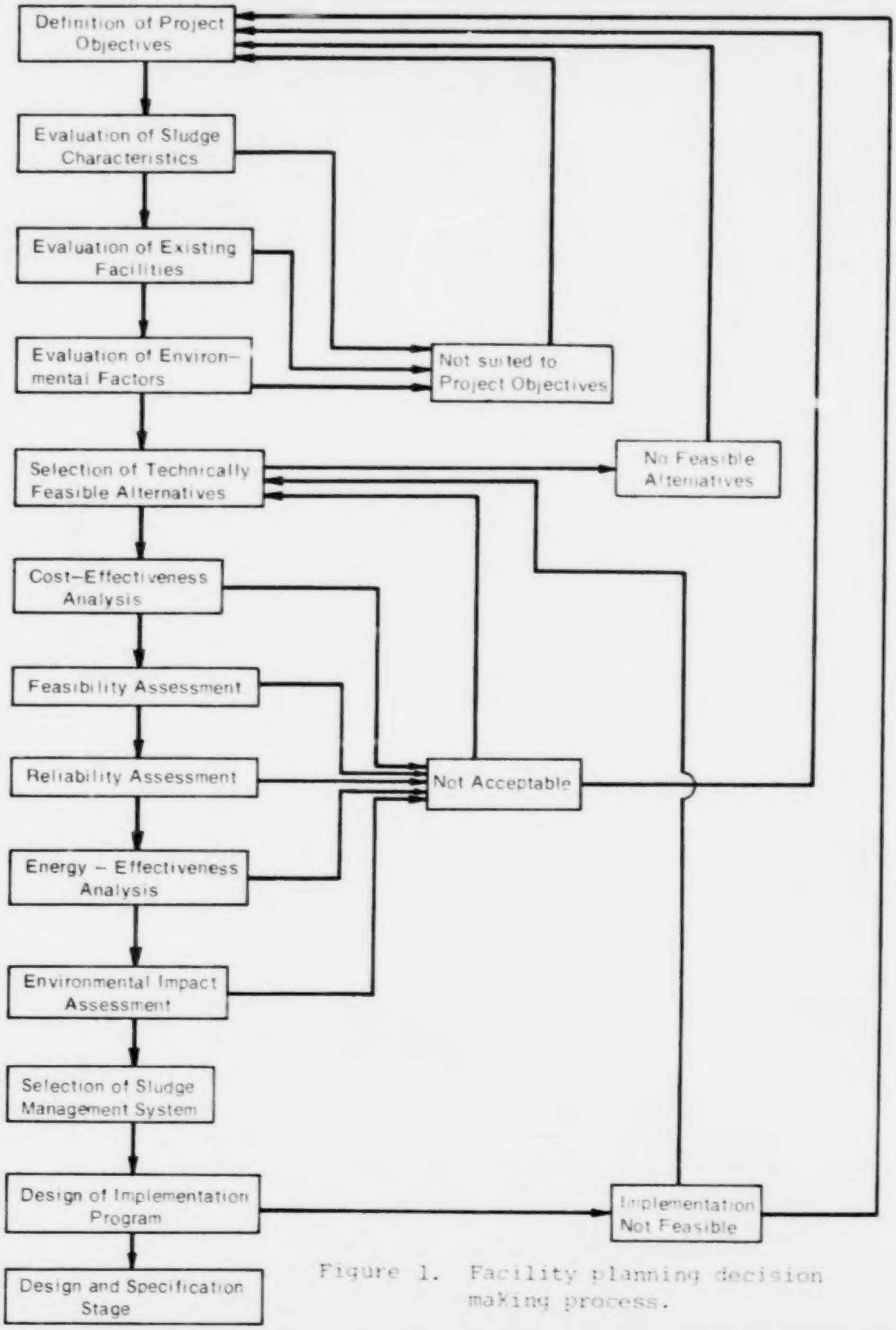
SCOPE

With very few exceptions, alternatives for sewage sludge management result in the ultimate disposal of the sludge in or on the land. Dumping of sludge in large bodies of water, especially ocean dumping, is currently practiced but national environmental policy calls for the cessation of water dumping in the near future. Disposal of sludge by dumping in large bodies of water will, therefore, not be considered in this report.

Sludge management systems consist of components which perform some combination of the following functions:

- Thickening
- Digestion
- Disinfection
- Conditioning
- Dewatering
- Combustion
- Drying
- Composting
- Land application
- Landfilling
- Off-site use
- Storage
- Transportation

Figure 2 illustrates the most common combinations of these elements. There are, of course, many other possible combinations which may be applicable in a specific situation, but the vast majority of plants will fit into one of the patterns in Figure 2. Sludge transport and storage can occur at any point in the system and are not shown. Sludge management systems are generally divided into sludge treatment and sludge disposal stages. Sludge treatment includes thickening, digestion, disinfection, conditioning and dewatering. Sludge disposal includes off-site use by others, landfill, and land application. Combustion, composting, and drying, are generally considered to be disposal processes although they are, strictly speaking, treatment processes. This publication deals with evaluating the selection and design of the disposal method, and those processes generally considered to be disposal methods; and sludge transport. It does not discuss in detail evaluating the selection and design of sludge treatment processes, except as they relate directly to the selection of the disposal method. This report is aimed at evaluating facility plans, designs and specifications, and operation and maintenance manuals for medium-to-large sludge management systems. The evaluator should use discretion in applying the checklists included herein to smaller systems.



Definition of Project Objectives
Evaluation of Sludge Characteristics
Evaluation of Existing Facilities
Evaluation of Environmental Factors
Not suited to Project Objectives
Selection of Technically Feasible Alternatives
No Feasible Alternatives
Cost-Effectiveness Analysis
Feasibility Assessment
Reliability Assessment
Not Acceptable
Energy – Effectiveness Analysis
Environmental Impact Assessment
Selection of Sludge Management System
Design of Implementation Program
Implementation Not Feasible
Design and Specification Stage

Figure 1. Facility planning decision making process.

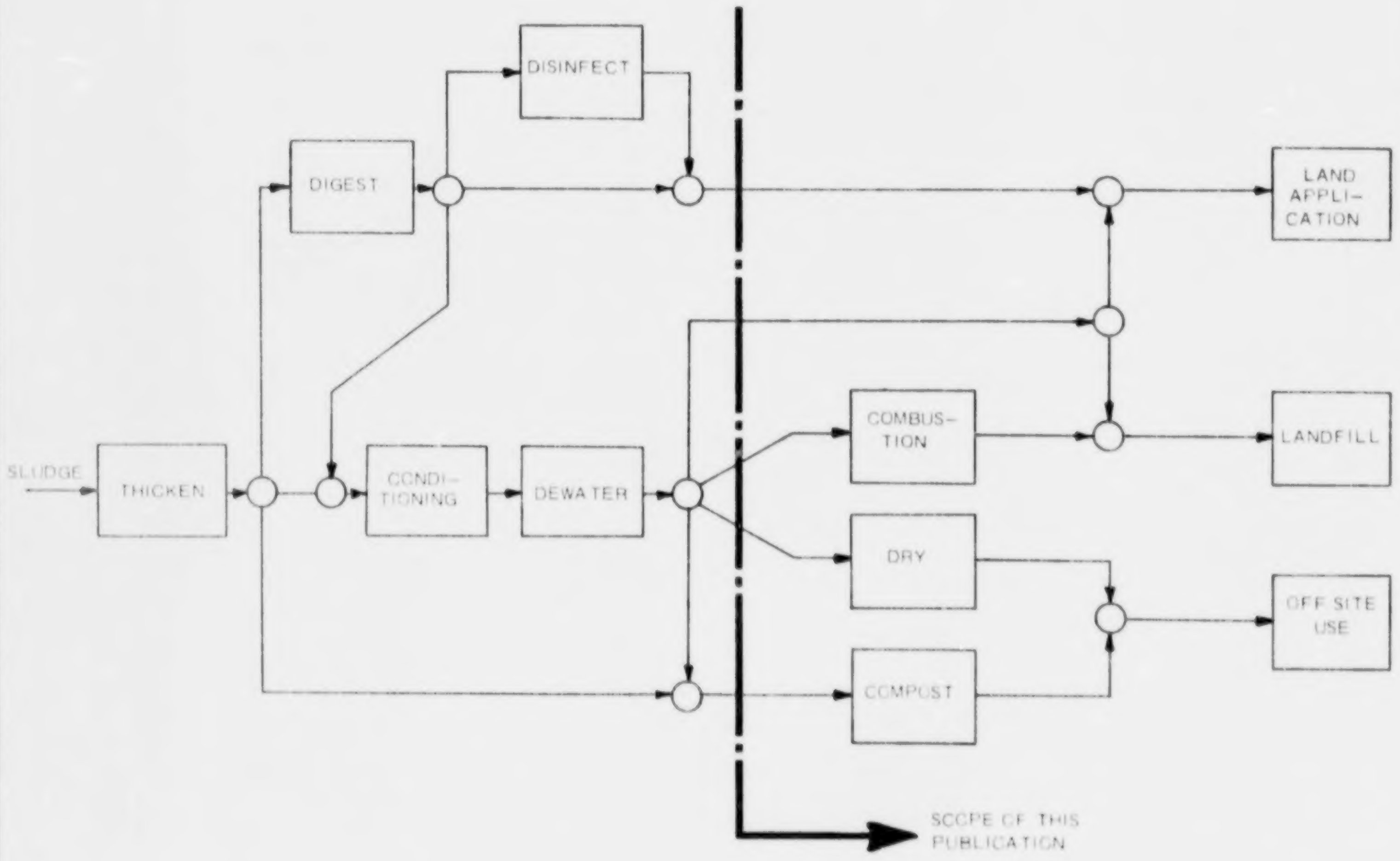

SLUDGE
THICKEN
DIGEST
DISINFECT
CONDI-TIONING
DEWATER
COMBUS-TION
DRY
COMPOST
LAND APPLI-CATION
LANDFILL
OFF SITE USE
SCOPE OF THIS PUBLICATION

Figure 2. Basic sludge management alternatives.

PART I

FACILITY PLANNING

FACILITY PLANNING

INTRODUCTION

The sludge management plan recommended in the facility plan must be the apparent best alternative derived from detailed evaluation of the technically feasible alternatives. Factors to be considered and weighed against each other in determining the best alternative are:

- Cost-effectiveness
- Energy-effectiveness
- Reliability
- Flexibility
- Environmental impacts

Part 1 emphasizes the careful preparation of a facility plan for sludge management and a thorough evaluation of that plan. It must be used in conjunction with Guidance for Preparing a Facility Plan (3). The facility plan should reflect a careful analysis of the merits of the technically feasible alternatives as well as the necessary tradeoffs among the goals of cost-effectiveness, energy-effectiveness, high reliability, high flexibility and environmental acceptability. The facility plan should present the final system selection in definitive form so that design plans and specifications may easily follow.

It is not the intent of this document to favor one management approach over another, as each system will have a combination of characteristics and criteria which are unique to that system. Certain specific sludge management systems, cyclonic incinerators for example, are not discussed in detail primarily because they are not in common use for sewage sludge management in the United States. Where such systems appear to have merit for the specific situation under considerations, the facility planner and evaluator should explore them in greater detail.

The decision-making process involved in the preparation of a facility plan does not readily lend itself to evaluation by rigid adherence to a checklist due to the many interlocking relationships among the decisions to be made. This checklist can be of value, however, if the user recognizes the complexity of the interrelationships among the steps in the decision-making process. It should also be recognized by the evaluator that certain alternatives can frequently be eliminated from consideration without detailed engineering analysis due to their obvious inapplicability to the case at hand. An example would be consideration of sludge transport by barge where no navigable waterways exist. This obviously does not merit evaluation and need not be considered.

There are 14 major categories in the Facility Plan Checklist:

A. Project Objectives
B. Characteristics of Sludge
C. Existing Facilities
D. Environmental Considerations
E. Sludge Transport

F. Land Application
G. Landfill
H. Combustion
I. Off-Site Use of Sludge by Others
J. Cost-Effectiveness Analysis
K. Reliability
L. Energy Analysis
M. Environmental Assessment
N. Implementation Program

Within each category are numerous sub-elements. All of the major categories should usually be included to insure selection of the most feasible alternative. It is not necessary that all the sub-elements be included. Sufficient detail should be provided to support the rejection of unfeasible alternatives and to insure that all critical factors in the proposed method were considered.

FACILITY PLANNING
CHECKLIST

A. PROJECT OBJECTIVES
   1. ENVIRONMENTAL PROTECTION
   2. SLUDGE UTILIZATION
   3. SLUDGE DISPOSAL
   4. CO-DISPOSAL WITH SOLID WASTE

B. CHARACTERISTICS OF SLUDGE
   1. QUANTITY, PRESENT AND PROJECTED
      a. Present, Projected, and Peak Flows
      b. Sludge Concentration
      c. Present, Projected, and Peak Solids
   2. ANALYSIS, PRESENT AND PROJECTED
      a. Physical Characteristics
      b. Organic Matter (VS, BOD, COD, TOC)
      c. Nutrients (Nitrogen, Phosphorus, Potassium)
      d. Sulfur
      e. Inorganic Ions, Heavy Metals
      f. Pathogen Content
      g. Heat Content
      h. pH
      i. Toxic Organic Compounds
   3. INDUSTRIAL CONTRIBUTIONS

C. EXISTING FACILITIES
   1. THICKENING
   2. DEWATERING
   3. STORAGE
   4. STABILIZATION
   5. COMBUSTION
   6. TRANSPORT
   7. DISPOSAL

D. ENVIRONMENTAL CONSIDERATIONS
   1. CLIMATE
      a. Precipitation Analysis
      b. Evapo-transpiration Potential
      c. Temperature Analysis
      d. Wind Analysis
   2. LAND CHARACTERISTICS
      a. Topography
      b. Soils
      c. Geology
      d. Groundwater
      e. Surface Water

E. SLUDGE TRANSPORT
   1. PIPELINE
      a. Route
      b. Size and Material

c. Pumping Requirements ________
2. TRUCK
a. Route and Travel Time ________
b. Size and Number of Trucks ________
c. Fuel Requirements ________
d. Manpower Requirements ________
e. Loading, Unloading, and Vehicle Service Facilities ________
3. BARGE
a. Route and Travel Time ________
b. Size and Number of Barges ________
c. Fuel Requirements ________
d. Manpower Requirements ________
e. Loading, Unloading, and Vehicle Service Facilities ________
f. Tow Tariffs ________
4. RAILROAD
a. Route and Travel Time ________
b. Size and Number of Cars ________
c. Fuel Requirements ________
d. Manpower Requirements ________
e. Loading, Unloading, and Service Facilities ________
f. Tariffs ________

F. LAND APPLICATION
1. PURPOSE
a. Dedicated Disposal ________
b. Agricultural Utilization ________
c. Reclamation of Disturbed or Marginal Lands ________
d. Combinations ________
2. EVALUATION OF POTENTIAL SITES
a. Geographical Location ________
(Proximity to surface and groundwaters, distance from treatment plant, proximity to transportation)
b. Compatibility with Land Use Plans ________
(Current and proposed future use, zoning and adjacent land use, proximity to current or proposed developed areas, room for future expansion)
c. Method of Land Acquisition ________
(Purchase, Lease, Purchase w/lease back, Contract w/user, Combination aquisition-lease)
3. STABILIZATION PROCESS
a. Anaerobic Digestion ________
b. Aerobic Digestion ________
c. Heat Treatment ________
d. Chemical Stabilization ________
4. AGRICULTURAL MANAGEMENT PLAN
a. Crops to be Grown, Rotation Plan and Markets ________
b. Farming by Municipal Agency or Contract ________
c. Long Range Plan ________
5. NUTRIENT BALANCE
a. Nitrogen
(1) Forms of Nitrogen in the Sludge ________
(2) Mineralization Rate of Organic Nitrogen ________

(3) Future Application Rate Adjustments for Mineralized Organic Nitrogen
(4) Additional Nitrogen Needed for Crop (if any)
b. Phosphorus
c. Potassium
6. HEAVY METAL LOADINGS
a. Cation Exchange Capacity
b. Sludge and Soil pH
c. Cadmium
Annual rate and total projected accumulation (lbs/acre)
d. Nickel
Annual rate and total projected accumulation (lbs/acre)
e. Copper
Annual rate and total projected accumulation (lbs/acre)
f. Molybdenum
Annual rate and total projected accumulation (lbs/acre)
g. Zinc
Annual rate and total projected accumulation (lbs/acre)
h. Lead
Annual rate and total projected accumulation (lbs/acre)
7. SLUDGE APPLICATION RATES
(Maximum annual rate tons per acre wet or dry, limiting factors, variations for crops, daily maximums)
8. SITE CONSIDERATIONS
a. Site Size
(1) Application Area
(2) Wet Weather Plan for Stockpile Storage or Alternative Disposal
(3) Buffer Area
(4) Expansion or Replacement Area
b. Compatiblity with Future Expansion
(Future process changes, changes in constituent levels, capacity increases.)
9. RUNOFF CONTROL
(Containment, recycle, or disposal)
10. STORAGE (Days of storage at design sludge production rate)
a. Capacity
b. Odor Control (Prior stabilization, mixing and/or aeration)
c. Drainage or Leachate Control
11. MONITORING PROGRAM
a. Monitoring Wells and Tests (Type and frequency)
b. Soil Tests (Type and frequency)
c. Sludge Tests (Type and frequency)
d. Crop Tissue Analysis

G. LANDFILL
1. METHOD
a. Sludge Only Trench Fill
(1) Narrow Trench
(2) Wide Trench

b. Sludge Only Area Fill
(1) Mound ________
(2) Layer ________
(3) Diked Containment ________
c. Co-disposal With Refuse
(1) Sludge refuse mixture ________
(2) Sludge soil mixture ________
2. SITE SELECTION
a. Identify Potential Sites ________
b. Public Participation Program ________
c. Technical Considerations
(1) Haul Distance ________
(2) Site Life and Size ________
(3) Topography ________
(4) Surface and Groundwater ________
(5) Soils and Geology ________
(6) Vegetation ________
(7) Environmentally Sensitive Areas ________
(8) Archaeological and Historical Significance ________
(9) Site Access ________
(10) Land Use ________
3. LEACHATE CONTROLS
a. Adequate Surface Drainage ________
b. Natural Attenuation ________
c. Containment ________
(Soil or membrane liner, leachate collection
and treatment)
4. GAS CONTROL ________
(Permeable or impermeable methods and/or extraction)
5. RUNOFF CONTROL ________
6. MONITORING ________

H. COMBUSTION
1. METHOD
a. Incineration
(1) Multiple Hearth ________
(2) Fluidized Bed ________
(3) Cyclonic Reactors, and Electric Incinerators ________
b. Pyrolysis ________
c. Wet Air Oxidation ________
d. Co-disposal with Solid Waste
(1) Total Co-disposal ________
(2) Refuse Derived Fuel ________
2. MASS BALANCE
a. Inputs
(1) Dry Solids and Moisture in Sludge ________
(2) Air Required for Combustion ________
(3) Other Factors ________
(auxiliary fuel, makeup sand, steam)
b. Outputs ________
(Ash, combustible gas, tar, char, water, CO_2, CO, SO_2,
N, sand, excess air)

3. ENERGY BALANCE
a. Inputs
(Solids heat of combustion, auxiliary fuel heat of combustion including afterburner)
b. Outputs
(Latent heat of free moisture and moisture of combustion. Sensible heat of gases of combustion, excess air, and moisture. Sensible heat of ash, radiation and conduction, sensible heat of shaft cooling air and recovered energy.)
4. USE OF RECOVERED ENERGY
a. On-site Use
(Combustion air preheating, space conditioning, sludge thermal conditioning, sludge digester heating, steam turbines, gas turbines, pyrolysis reactor heating.)
b. Off-site use
(Combustible gas, tar (oil), char, steam, electricity.)
5. ASH DISPOSAL
a. Transport
b. Dewatering
c. Land Application
d. Landfill
e. Off-site Use By Others
6. AIR QUALITY CONTROL
(Scrubbers, afterburners, electrostatic precipitators.)
7. FUELS
(Gas, oil, refuse derived fuel, powdered coal.)

I. SLUDGE FOR OFF-SITE USE BY OTHERS
1. MARKET ANALYSIS
a. Intended market
(1) Governmental Agencies
(Highway departments, municipal parks, golf courses, and stadiums, forestry departments.)
(2) Wholesalers or processors
(3) Private users
(Golf courses and stadiums, nurseries, agriculture, individuals.)
b. Capacity of Market to Absorb Product
c. Market Value of Product
d. Packaging Requirement
2. PROCESSING METHOD
a. Drying
(1) Drying beds
(2) Drying lagoons
(3) Heat drying
(a) Flash drying
(b) Rotary kiln drying
b. Composting
(1) Windrow
(2) Static Pile

(3) Mechanical System ________
c. Co-disposal with Solid Waste
(1) Refuse as Bulking Agent ________
(2) Sludge as Nutrient and Moisture Source ________
d. Nutrient Enrichment Considered ________
3. PACKAGING AND DELIVERY ________
(Pick up by user, bulk delivery to user, bagged)

J. COST-EFFECTIVENESS ANALYSIS
1. GENERAL CONSIDERATIONS
a. Planning Period ________
b. Discount Rate ________
c. Construction or Other Cost Indices ________
d. Service Lives of Facility and Equipment ________
e. Capital Costs and Credits ________
f. Fixed Annual Costs ________
g. Variable Annual Costs and Credits ________
2. SLUDGE TREATMENT
a. Capital Costs
(1) Land Acquisition ________
(2) Facility Construction ________
(3) Filtrate, Centrate, or Supernatant Treatment Facilities ________
(4) Impact of Chemical Addition on Other Treatment Process ________
b. Fixed annual costs
(1) Labor ________
(2) Maintenance ________
(3) Monitoring ________
(4) Supplies ________
c. Variable Annual Costs and Credits
(1) Power ________
(2) Auxiliary Fuel ________
(3) Chemicals ________
(4) Filtrate, Centrate, or Supernatant Treatment ________
(5) Impact of Chemical Addition on Other Treatment Processes ________
(6) Value of Recovered Digester Gas ________
3. SLUDGE TRANSPORT
a. Capital Costs
(1) Right-of-way Acquisition ________
(2) Vehicle Purchase ________
(3) Pipeline Construction ________
(4) Facilities Construction ________
b. Fixed Annual Costs
(1) Labor ________
(2) Maintenance ________
(3) Vehicle Leasing ________
(4) Supplies ________
c. Variable Annual Costs
(1) Pumping Energy ________
(2) Vehicle Fuel ________
(3) Contract Haul Costs ________

4. LAND APPLICATION
    a. Capital Costs
        (1) Land Acquisition ________
        (2) Equipment Purchase ________
        (3) Site Preparation ________
        (4) Facilities Construction ________
        (5) Value of Reclaimed Land ________
    b. Fixed Annual Costs
        (1) Land Leasing ________
        (2) Labor ________
        (3) Maintenance ________
        (4) Equipment Leasing ________
        (5) Monitoring ________
        (6) Supplies ________
    c. Variable Annual Cost or Credit
        (1) Equipment Fuel ________
        (2) Supplemental Fertilizer ________
        (3) Credit for Sale or Cost for Disposal of Crop ________
5. LANDFILL
    a. Capital Costs or Credits
        (1) Land Acquisition ________
        (2) Equipment Purchase ________
        (3) Site Preparation ________
        (4) Facilities Construction ________
        (5) Runoff and Leachate Treatment Facilities ________
        (6) Value of Reclaimed Land ________
    b. Fixed Annual Costs
        (1) Land Leasing ________
        (2) Labor ________
        (3) Maintenance ________
        (4) Equipment Leasing ________
        (5) Runoff Treatment ________
        (6) Monitoring ________
        (7) Supplies ________
    c. Variable Annual Costs or Credits
        (1) Equipment Fuel ________
        (2) Leachate Treatment ________
        (3) Value of Collected Gas ________
6. COMBUSTION
    a. Capital Costs
        (1) Reduction Facility Construction ________
        (2) Scrubber Effluent Treatment Facilities ________
        (3) Liquor Treatment Facilities ________
        (4) Ash Disposal Facilities ________
    b. Fixed Annual Costs
        (1) Labor ________
        (2) Maintenance ________
        (3) Monitoring ________
        (4) Supplies ________
    c. Variable Annual Costs or Credits
        (1) Auxiliary Fuel ________
        (2) Power ________

            - (3) Ash Handling and Disposal ________
            - (4) Value of Residues
                - (a) Gas ________
                - (b) Tar ________
                - (c) Char ________
                - (d) Ash ________
            - (5) Value of Energy Recovered ________
            - (6) Scrubber Effluent Treatment ________
            - (7) WAO Liquor Treatment ________
    - 7. SLUDGE FOR OFF-SITE USES BY OTHERS
        - a. Capital Costs
            - (1) Land Acquisition ________
            - (2) Equipment Purchase ________
            - (3) Facility Construction ________
        - b. Fixed Annual Costs
            - (1) Labor ________
            - (2) Maintenance ________
            - (3) Monitoring ________
            - (4) Supplies ________
        - c. Variable Annual Cost or Credit
            - (1) Equipment Fuel ________
            - (2) Power ________
            - (3) Packaging ________
            - (4) Bulking Agent ________
            - (5) Value of Product ________

- K. RELIABILITY
    - 1. MECHANICAL DOWNTIME
        - a. Standby Power Supply ________
        - b. Standby Fuel Supply ________
        - c. Storage ________
        - d. Duplicate Equipment ________
        - e. Backup Equipment
            - (1) At Site ________
            - (2) At Other Sites ________
            - (3) Leaseable ________
        - f. Alternative Management Techniques ________
    - 2. AVAILABILITY OF NEEDED RESOURCES
        - a. Electric Power ________
        - b. Fuel ________
        - c. Chemicals ________
        - d. Manpower ________
        - e. Replacement Parts ________
    - 3. FACTORS OF SAFETY ________

- L. ENERGY ANALYSIS ________

- M. ENVIRONMENTAL ASSESSMENT
    - 1. ENVIRONMENTAL IMPACTS
        - a. Soil and Vegetation ________
        - b. Groundwater ________
        - c. Surface Water ________

- d. Animal and Insect Life
- e. Air Quality
- f. Climate

2. PUBLIC HEALTH IMPACTS
    - a. Disease Vectors
    - b. Soil and Vegetation
    - c. Groundwater Quality
    - d. Surface Water Quality
    - e. Air Quality
3. SOCIAL IMPACTS
    - a. Relocation of Residents
    - b. Greenbelts and Open Spaces
    - c. Recreational Activity
    - d. Community Growth
    - e. Noise and Odor
4. ECONOMIC IMPACT
    - a. Property Values
    - b. Overall Local Economy
    - c. Taxation
    - d. Conservation of Resources and Energy

N. IMPLEMENTATION PROGRAM

1. PUBLIC PARTICIPATION PROGRAM
    - a. Planning Stage
    - b. Design Stage
    - c. Construction Stage
    - d. Operational Stage
2. POTENTIAL ROADBLOCKS
3. LAND ACQUISITION PROGRAM
    - a. Purchase
    - b. Lease
    - c. Condemnation
    - d. Land Dedication
4. IMPLEMENTATION SCHEDULE
    - a. Facility Plan Approval
    - b. Land Acquisition
    - c. Design
    - d. Design Approval
    - e. Construction
    - f. Operation
5. STAFFING PLAN
    - a. Operations
    - b. Maintenance
    - c. Supervisory
    - d. Laboratory
    - e. Administrative
6. COMPATIBILITY WITH REGULATIONS
    - a. Zoning and Land Use
    - b. Solid Waste Disposal
    - c. Air Pollution Control
    - d. Water Pollution Control
    - e. Public Health

FACILITY PLANNING
SUPPORTING COMMENTARY

Section A - PROJECT OBJECTIVES

The basic project goal is to provide for sludge management in a cost-effective and environmentally acceptable manner. In order to accomplish this goal, the specific objectives and goals of the sludge management system must be clearly defined in the facility plan. The successful implementation of the plan depends primarily on the formulation and appropriateness of these goals. It is imperative that the goals relative to sludge reuse and co-disposal with solid waste established in the initial phase of facility planning be re-evaluated throughout the planning process.

A.1. ENVIRONMENTAL PROTECTION

The facility plan should establish goals for the environmentally sound management of sludge. These goals should take into account the following factors, which are discussed in greater detail in the appropriate sections of this document.

- Groundwater protection
- Surface water protection
- Air quality protection
- Land protection

A.2. SLUDGE UTILIZATION

The facility plan must establish goals for utilization or disposal of sludge. In many, but not all instances, consideration of the sludge as a resource rather than as a material to be disposed of can result in a more cost-effective solution to the sludge management problem. Among the utilization operations which have been proposed or implemented are:

- Use of sludge as a soil conditioner or fertilizer
- Use of sludge as fill material for land reclamation
- Use of sludge as an energy source
- Use of sludge (ash) as a concrete or asphalt additive
- Use of sludge as a raw material for manufacture of activated carbon

A.3. SLUDGE DISPOSAL

Where sludge utilization is not feasible, sludge disposal must be practiced. Sludge disposal alternatives include landfill and lagoon operations and land application of sludge to a dedicated site. Incinerator ash is most often disposed of rather than utilized.

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A.4. CO-DISPOSAL WITH SOLID WASTE

Consideration should be given (4) to co-disposal of sludge with solid wastes. This may result in significant improvements in the cost-effectiveness of disposal of both materials. In considering co-disposal alternatives, it is important to remember the differences as well as the similarities between sludge and solid waste. These differences are summarized in Table 1.

TABLE 1. QUALITATIVE COMPARISON OF MUNICIPAL SLUDGE WITH MUNICIPAL SOLID WASTE

Property	Comparison
Volume	The per capita volume of solid waste is much greater than sludge (typically 5.72 lb/cap/day vs 0.14 lb/cap/day) (5, 6).
Moisture content	The moisture content of sludge is typically higher than that of solid waste.
Heat content	Solid waste has a higher heat content than sludge
Homogeneity	Sludge is much more homogeneous than solid waste.
Nutrient content	Sludge has a higher concentration of the nutrients required for biological growth than solid waste.

These differences present opportunities for improving disposal cost-effectiveness as well as problems involved in combining the materials. Typical co-disposal techniques include:

- Co-incineration or co-pyrolysis
- Co-disposal by landfill
- Use of refuse as an auxiliary fuel in sludge incineration
- Use of refuse as a bulking agent in sludge composting
- Use of sludge as a moisture and nutrient source in solid waste composting
- Use of sludge as a soil conditioner for solid waste landfill cover

Section B - CHARACTERISTICS OF SLUDGE

An evaluation of the characteristics of the sludge is an essential step in selecting sludge management alternatives, and may provide a basis of preliminary screening of methods. The best available data should be used in establishing the sludge characteristics. Actual flow data and laboratory analyses are always preferrable, but it is often necessary to estimate sludge characteristics based on typical values or on the experiences of similar treatment plants. This is always true in the case of a new or upgraded wastewater treatment facility.

B.1. QUANTITY, PRESENT AND PROJECTED

A detailed analysis of the future sludge flow is required on both liquid and dry solids basis. The analysis should include data or estimates describing the following:

- Initial sludge flow, concentration and dry solids production
- Future sludge flow, concentration and dry solids production
- Seasonal variations in sludge flow, concentration and dry solids production

Future sludge quantities should be estimated from population and industrial growth projections. Consideration should also be given to planned process modifications that will affect sludge production.

It is generally possible to control short-term peaks in sludge and solids production by storage within wastewater and sludge treatment process units, reducing their effect on the sludge management system. Consideration should be given to peaks which are in excess of those which can be successfully stored.

Table 2 is a summary of typical sludge production rates for various treatment processes. The EPA Process Design Manual for Sludge Treatment and Disposal (1, 7) contains additional information useful for estimating sludge production quantities.

B.2. ANALYSIS, PRESENT AND PROJECTED

The analysis of the sludge will have as great an impact on the selection of sludge management techniques as will the quantity. Sludge analysis varies widely from plant-to-plant due to such factors as wastewater treatment processes, industrial contributions, water supply quality, and the presence or absence of storm water in the collection system. Table 3 summarizes typical chemical components of sewage sludges in 150 treatment plants in the northcentral and eastern United States.

B.2.a. Physical Characteristics

Because the nature of sludges resulting from the treatment of municipal wastewaters varies so greatly from one locale to another, generalized statements about their physical characteristics are of limited value. However, some observations which are usually true follow.

TABLE 2. NORMAL QUANTITIES OF SLUDGE PRODUCED BY DIFFERENT TREATMENT PROCESSES[1] (5)

Treatment process	Normal quantity of sludge						Dry solids	
	Gal/ million gal of sewage	Tons/ million gal of sewage	Cu ft/ 1,000 persons daily	Moisture, %	Specific gravity of sludge solids	Specific gravity of sludge	Lb/ million gal of sewage	Lb/ 1,000 persons daily
Primary sedimentation:								
Undigested	2,950	12.5	39.0	95	1.40	1.02	1,250	125
Digested in separate tanks	1,450	6.25	19.0	94	-	1.03	750	75
Digested and dewatered on sand beds	-	0.94	5.7	60	-	-	750	75
Digested and dewatered on vacuum filters	-	1.36	4.3	72.5	-	1.00	750	75
Trickling filter	745	3.17	9.9	92.5	1.33	1.025	476	48
Chemical precipitation:	5,120	22.0	68.5	92.5	1.93	1.03	3,300	330
Dewater on vacuum filters	-	6.0	19.3	72.5	-	-	3,300	330
Primary sedimentation and activated sludge:								
Undigested	6,900	29.25	92.0	96	-	1.02	2,340	234
Undigested and dewatered on vacuum filters	1,480	5.85	20.0	80	-	0.95	2,340	234
Digested in separate tanks	2,700	11.67	36.0	94	-	1.03	1,400	140
Digested and dewatered on sand beds	-	1.75	18.0	60	-	-	1,400	140
Digested and dewatered on vacuum filters	-	3.5	11.7	80	-	0.95	1,400	140
Activated sludge:								
Wet sludge	19,400	75.0	258.0	98.5	1.25	1.005	2,250	225
Dewatered on vacuum filters	-	5.62	19.0	80	-	0.95	2,250	225
Dried by heat dryers	-	1.17	3.0	4	-	1.25	2,250	225
Septic tanks, digested	900	-	12.0	90	1.40	1.04	810	81
Imhoff tanks, digested	500	-	6.7	85	1.27	1.04	690	69

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[1] Based on a sewage flow of 100 gpcd and 300 ppm, or 0.25 lb per capita daily, of suspended solids in sewage.

TABLE 3. MAJOR COMPONENTS OF STABILIZED SLUDGE (8)*

	Sample				
Component	Type	Number	Range	Median	Mean
			----------------mg/l----------------		
NO3-N, mg/l	Anaerobic	35	2 - 4,900	79	520
	Aerobic	8	7 - 830	180	300
	Other	3	-- ---	---	780
	All	45	2 - 4,900	140	490
NH4-N, mg/l	Anaerobic	67	120 - 67,600	1,600	9,400
	Aerobic	33	30 - 11,300	400	950
	Other	3	5 - 12,500	80	4,200
	All	103	5 - 67,600	920	6,540
			----------------%----------------		
Total N, %	Anaerobic	85	0.5 - 17.6	4.2	5.0
	Aerobic	38	0.5 - 7.6	4.8	4.9
	Other	68	0.1 - 10.0	1.8	1.9
	All	191	0.1 - 17.6	3.3	3.9
Organic C, %	Anaerobic	31	18 - 39	26.8	27.6
	Aerobic	31	27 - 37	29.5	31.7
	Other	60	6.5 - 48	32.5	32.6
	All	101	6.5 - 48	30.4	31.0
Total P, %	Anaerobic	86	0.5 - 14.3	3.0	3.3
	Aerobic	38	1.1 - 5.5	2.7	2.9
	Other	65	0.1 - 3.3	1.0	1.3
	All	189	0.1 - 14.3	2.3	2.5
Total S, %	Anaerobic	19	0.8 - 1.5	1.1	1.2
	Aerobic	9	0.6 - 1.1	0.8	0.8
	Other	--	-- --	--	--
	All	28	0.6 - 1.5	1.1	1.1
K, %	Anaerobic	86	0.02- 2.64	0.30	0.52
	Aerobic	37	0.08- 1.10	0.38	0.46
	Other	69	0.02- 0.87	0.17	0.20
	All	192	0.02- 2.64	0.30	0.40
Na, %	Anaerobic	73	0.01- 2.19	0.73	0.70
	Aerobic	36	0.03- 3.07	0.77	1.11
	Other	67	0.01- 0.96	0.11	0.13
	All	176	0.01- 3.07	0.24	0.57
Ca, %	Anaerobic	87	1.9 - 20.0	4.9	5.8
	Aerobic	37	0.6 - 13.5	3.0	3.3
	Other	69	0.1 - 25.0	3.4	4.6
	All	193	0.1 - 25.0	3.9	4.9
Mg, %	Anaerobic	87	0.03- 1.92	0.48	0.58
	Aerobic	37	0.03- 1.10	0.41	0.52
	Other	65	0.03- 1.97	0.43	0.50
	All	189	0.03- 1.97	0.45	0.54

(Continued)

TABLE 3. (Continued)

	Sample				
Component	Type	Number	Range	Median	Mean
			%		
Ba, %	Anaerobic	27	0.01- 0.90	0.05	0.08
	Aerobic	10	0.01- 0.03	0.02	0.02
	Other	23	0.01- 0.44	0.01	0.04
	All	60	0.01- 0.90	0.02	0.06
Fe, %	Anaerobic	96	0.1 - 15.3	1.2	1.6
	Aerobic	38	0.1 - 4.0	1.0	1.1
	Other	31	0.1 - 4.2	0.1	0.8
	All	165	0.1 - 15.3	1.1	1.3
Al, %	Anaerobic	73	0.1 - 13.5	0.5	1.7
	Aerobic	37	0.1 - 2.3	0.4	0.7
	Other	23	0.1 - 2.6	0.1	0.3
	All	133	0.1 - 13.5	0.4	1.2
			mg/kg		
Mn, mg/kg	Anaerobic	81	58 - 7,100	280	400
	Aerobic	38	55 - 1,120	340	420
	Other	24	18 - 1,840	118	250
	All	143	18 - 7,100	260	380
B, mg/kg	Anaerobic	62	12 - 760	36	97
	Aerobic	29	17 - 74	33	40
	Other	18	4 - 700	16	69
	All	109	4 - 760	33	77
As, mg/kg	Anaerobic	3	10 - 230	116	119
	Aerobic	--	-- --	---	---
	Other	7	6 - 18	9	11
	All	10	6 - 230	10	43
Co, mg/kg	Anaerobic	4	3 - 18	7.0	8.8
	Aerobic	--	-- --	---	---
	Other	9	1 - 11	4.0	4.3
	All	13	1 - 18	4.0	5.3
Mo, mg/kg	Anaerobic	9	24 - 30	30	29
	Aerobic	3	30 - 30	30	30
	Other	17	5 - 39	30	27
	All	29	5 - 39	30	28
Hg, mg/kg	Anaerobic	35	0.5 - 10,600	5	1,100
	Aerobic	20	1.0 22	5	7
	Other	23	2.0 - 5,300	3	810
	All	78	0.5 - 10,600	5	733
Pb, mg/kg	Anaerobic	98	58 - 19,730	540	1,640
	Aerobic	57	13 - 15,000	300	720
	Other	34	72 - 12,400	620	1,630
	All	189	13 - 19,700	500	1,360

(Continued)

TABLE 3. (Continued)

	Sample				
Component	Type	Number	Range	Median	Mean
			----------mg/kg----------		
Zn, mg/kg	Anaerobic	108	108 - 27,800	1,890	3,380
	Aerobic	58	109 - 14,900	1,800	2,170
	Other	42	101 - 15,100	1,100	2,140
	All	208	101 - 27,800	1,740	2,790
Cu, mg/kg	Anaerobic	108	85 - 10,100	1,000	1,420
	Aerobic	58	85 - 2,900	970	940
	Other	39	84 - 10,400	390	1,020
	All	205	84 - 10,400	850	1,210
Ni, mg/kg	Anaerobic	85	2 - 3,520	85	400
	Aerobic	46	2 - 1,700	31	150
	Other	34	15 - 2,800	118	360
	All	165	2 - 3,800	82	320
Cd, mg/kg	Anaerobic	98	3 - 3,410	16	106
	Aerobic	57	5 - 2,170	16	135
	Other	34	4 - 520	14	70
	All	189	3 - 3,410	16	110
Cr, mg/kg	Anaerobic	94	24 - 28,850	1,350	2,070
	Aerobic	53	10 - 13,600	260	1,270
	Other	33	22 - 99,000	640	6,390
	All	180	10 - 99,000	890	2,620

*Dissolved substances reported as weight per unit volume of sludge of mg/l; particulates are reported as weight per unit sludge either as a percent of total solids for major constituents, or as mg per kg total solids for trace constituents.

Raw primary sludges settle, thicken and dewater with relative ease compared to secondary biological sludges due to their coarse, fibrous nature. Generally, at least 30% of the solids are larger than 30 mesh in size. These coarse particles permit rapid formation of a sludge cake with sufficient structural matrix to permit good solids capture and rapid dewatering. Anaerobic digestion of primary sludges frequently makes them more difficult to thicken and dewater. However, the dewatering results attainable at relatively low costs are still generally good.

Activated sludges show much greater variation in dewatering characteristics than do primary sludges. These variations may even be substantial from day-to-day at the same plant. The sludges are much finer than primary sludges and are largely cellular organic material with a density very nearly the same as water. They are much more difficult to dewater than primary sludges.

The nature of sludges resulting from chemical coagulation of sewage depends on the nature of the coagulant used. Generally, alum and iron coagulants produce gelatinous floc which is difficult to dewater. Lime coagulation produces a sludge which readily thickens and dewaters in most cases. Estimates of sludge characteristics from a variety of wastewater processes may be found in EPA's Process Design Manual for Sludge Treatment and Disposal (1).

The physical characteristics of the sludge will affect the selection of sludge treatment processes and ultimate disposal. The difficulty of dewatering waste activated sludge, for example, may preclude the use of incineration because it may not be possible to obtain a sludge cake capable of sustaining autogenous or economical burning.

B.2.b. Organic Matter (VS, BOD, COD, TOC)

The organic content of sludge is expressed in terms of its Volatile Solids (VS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), or total organic carbon (TOC). Methods for determining these values are given in Standard Methods (9). Another measure of organic content which is useful in the evaluation and design of combustion processes is the theoretical oxygen demand (THOD). This is the oxygen required to completely oxidize the major constituents of the sludge, based on stochiometric relationships. The organic content of sludge affects:

- Biological decomposition rate
- Heat value
- Potential for odor
- Value as a soil conditioner

B.2.c. Nutrients (Nitrogen, Phosphorus, Potassium)

Nitrogen is present in sludge in the form of organic nitrogen, ammonium ions, nitrates and nitrites. The concentrations of all forms are customarily expressed as equivalent nitrogen; that is, a sludge with an actual nitrate ion concentration of 2,000 mg/kg (ppm) would be said to have a concentration of 2,000 mg/kg x 14 (molecular weight of N) ÷ 62 (molecular weight of NO_3) = 452 mg/kg as N. Nitrogen in the nitrate form is important because it is highly mobile and can contaminate groundwater at land application and landfill sites. Nitrogen is an essential nutrient for all forms of life and, as such, will affect the decomposition rate of sludge, its value as a fertilizer, and its potential for surface water contamination.

Phosphorus is found in sludges in many forms, including the phosphate and orthophosphate ions. Concentrations of phosphorus or any of its constituent ions are normally expressed as phosphorus, although they may be expressed as phosphoric acid, P_2O_5, which is a method sometimes used in the fertilizer industry. Phosphorus is an essential nutrient for bacterial decomposition and for plant growth, and can affect both the rate of sludge decomposition and the value of the sludge as fertilizer. Additionally, the nutrient value of the phosphorus affects the potential for surface water pollution from sludge disposal or utilization. Excess phosphorus applications can result in phytotoxicity in some plants.

The potassium concentration is often expressed in terms of potash K_2O rather than potassium as that is a method often used by the fertilizer industry for expressing potassium concentrations. Potassium is a vital plant nutrient, but is rarely found in commercially usable concentrations in sludge.

B.2.d. Sulfur

Sulfur is present in sludge in the form of sulfates and sulfides, usually expressed as sulfur. Sulfur is of importance because of its role in anaerobic decomposition of sludge and in the production of odors (hydrogen sulfide). An additional problem associated with sulfur is the possible formation of sulfuric acid and resultant corrosion. If combustion of sludges with high sulfur content is contemplated, the possibility of sulfur dioxide production should also be explored.

B.2.e. Inorganic Ions, Heavy Metals

Inorganic ion concentrations are significant because of their potential for air, land, and water pollution and their potentially toxic effect on plants, animals, and humans. Not to be neglected, however, is the fact that most of the inorganic ions which may be toxic in high concentrations are also essential micronutrients required by plants and animals.

Among the possible deleterious effects of inorganic ions are:

- Increases in soil, groundwater, and surface water salinity.
- Toxic effects on crops from high concentrations of such heavy metals as zinc, boron, copper, and nickel.
- Toxic effects on humans or animals due to excess plant uptake of such heavy metals as cadmium, molybdenum, and zinc.
- Air pollution from volatilization of lead and mercury in combustion processes.
- Groundwater pollution by leaching of heavy metals from sludge.

B.2.f. Pathogen Content

Pathogen content measured by the fecal coliform, salmonella, and ascaris egg tests, is normally quite low in well stabilized sludges. Pathogen content of sludge is of particular concern in any sludge management alternative involving food chain crops, use of a sludge product by the public, or potential contamination of ground or surface waters.

B.2.g. Heat Content

The heat content (heat of combustion) of the sludge is of importance in evaluating sludge combustion techniques. Typical values are shown in Table 4.

TABLE 4. TYPICAL HEAT OF COMBUSTION OF SLUDGES (TOTAL DRY SOLIDS BASIS) (10)

Material	Combustibles %	Ash (%)	Average BTU/pound
Grease and scum	88.5	11.5	16,800
Raw sewage solids	74.0	26.0	10,300
Fine screenings	86.4	13.6	9,000
Ground garbage	84.8	15.2	8,200
Digested sewage solids and ground garbage	49.6	50.4	8,000
Digested sludge	59.6	40.4	5,300
Grit	33.2	69.8	4,000

If the available heat of combustion from the sludge equals or exceeds the heat required to dry and ignite the sludge and to compensate for heat losses from the system, then the sludge incineration process is autogenous (self-burning), and very little external energy is required, except for furnace start-up. If the heat or moisture content of the sludge is such that autogenous burning is not possible, operating costs must include auxiliary fuel requirements for combustion and for afterburning of stack gasses.

The heat content of the sludge can be approximated by the heat released in the oxidation of the primary constituents of the sludge, given estimates of their concentrations (11). Several other methods of calculation which have been proposed give similar, but varying results (11-13). The accuracy of heat content calculation is questionable, however, and actual calorimeter tests should be used whenever possible (10).

B.2.h. pH

The pH of the sludge has an impact on the availability of heavy metals and the pathogen concentration of the sludge. High pH (above 11), in general, promotes the destruction of pathogens and inhibits the movement of heavy metals through the soil and the uptake of heavy metals by plants.

B.2.i. Toxic Organic Compounds

Toxic organic compounds, which are persistent in the environment, such as pesticides and polychlorinated biphenyls (PCB's), are of concern where the sludge management system may result in discharge of these substances to the atmosphere, groundwater, or surface waters, or allow their entry into human or animal food chains. Uptake by plants is unlikely. The pathways of major concern are contamination of plant or soil surfaces.

B.3. INDUSTRIAL CONTRIBUTIONS

The industrial contributions to the wastewater should be analyzed to determine their effects on the sludge production rate (both average quantity and peak quantities, especially seasonal peaks) and on the sludge analysis. Some industries are a major potential source of toxic substances such as heavy metals. The facilities plan should evaluate whether pretreatment is required for industrial wastes by the "Federal Pretreatment Standards" (40CFR128) (14) or any state or local pretreatment standard for removal of toxic substances.

Section C - EXISTING FACILITIES

The existing sludge treatment and management facilities will be an important factor in the economics of sludge management alternative selection. Extensive existing facilities will, of course, tend to favor those alternatives which make effective use of those facilities. Existing facilities must be evaluated as to their reasonable future life and continued effectiveness. Sludge processing facilities which perform some combination of the following functions may be present:

- Thickening
- Dewatering
- Storage
- Stabilization
- Combustion
- Transport
- Disposal

Section D - ENVIRONMENTAL CONSIDERATIONS

Environmental considerations are those features of the environment which affect the selection of a sludge management system.

D.1. CLIMATE

A climatalogical analysis is important in the selection of most sludge management alternatives. While certain factors are of more concern for some systems than others, all factors should be considered to aid the decision-making process. The possibility of climatalogical variations within the planning area should also be considered. Sources of climatalogical data include (15):

- National Weather Service local offices
- Climatalogical Data, Published by the National Weather Service, Department of Commerce
- Airports
- Universities
- Military installations
- Agricultural extension services
- Agricultural experiment stations

- Agencies managing large reservoirs
- American Society of Heating and Refrigeration Engineers publications

D.1.a. Precipitation Analysis

The precipitation analysis will affect the choice of ultimate disposal method, the selection of crops for land application, and the scheduling of land application and landfill operations, as well as many other features of land application and landfill systems. The precipitation analysis should include the following minimum information:

- Mean annual rainfall
- Seasonal distribution
- Storm intensity

D.1.b. Evapotranspiration Potential

The evapotranspiration potential affects crop selection and application rates for agricultural utilization of sludge. Evaporation rates effect sludge processing methods such as composting, sandbed drying and lagoon drying. Analysis of evaporation rates and evapotranspiration potentials should include:

- Mean annual rates
- Seasonal variations

D.1.c. Temperature Analysis

The temperature analysis is important in the selection of crops in land application systems and in scheduling of landfill and land application operations. The temperature analysis should include:

- Mean annual temperature
- Seasonal variations
- Number of frost-free days
- Number of freezing days

D.1.d. Wind Analysis

The wind analysis will affect the design of incinerator stacks and the siting and design of landfill and land application sites. Wind data should include the average and design maximum velocities, and the prevailing direction.

D.2. LAND CHARACTERISTICS

Land characteristics are of critical importance in the selection of the ultimate disposal method.

Sources of land characteristics data include (15):

- U.S. Department of Agriculture - Commodity Stabilization Program
- U.S. Department of Agriculture - Soil Conservation Service
- U.S. Department of Agriculture - Extension Service
- U.S. Geological Survey
- U.S. Environmental Protection Agency (STORET)
- Local planning departments
- U.S. Corps of Engineers offices
- Private photogrammetry and mapping companies
- State mine and geology agencies
- State water resources agencies
- Local water conservation districts
- Groundwater users (municipalities, water companies, individuals, etc.)

D.2.a. Topography

The topography will, to a large extent, determine the design of the ultimate disposal system and affects the potential of the site for runoff and subsequent surface and groundwater pollution.

D.2.b. Soils

The data describing soils should include the following:

- Depth
- Texture
- Structure
- Bulk densities
- Porosity
- Permeability
- Moisture
- Ease of excavation
- Stability
- pH
- Cation exchange capacity

D.2.c. Geology

The geologic data should include the following:

- Depth
- Type
- Fractures
- Surface outcrops

D.2.d. Groundwater

Groundwater data are important because of the necessity of protecting the aquifers from leachate pollution. Groundwater data should include:

- Depth to groundwater
- Depth of aquifer
- Direction of flow
- Hydraulic gradeline
- Quality
- Location of recharge zones
- Present and future uses

D.2.e. Surface Water

Surface water data should include:

- Location of surface waters
- Direction of flow
- Rate of flow
- Quality
- Present and intended uses

Section E - SLUDGE TRANSPORT

The evaluation of sludge transport systems requires the examination of several factors. The quantity and type of sludge and degree of processing it receives influence the means of transport as does the method of ultimate disposal. Environmental considerations and the availability of transport facilities also influence the decision-making process. Barging, for example, will be precluded from consideration if there is no appropriate watercourse between the processing and disposal sites. In the preliminary analysis of alternatives, it should be readily apparent that certain transport modes are unsuitable for the particular local conditions.

There are four basic methods of sludge transport-pipeline, truck, barge and railroad. In certain instances, the methods may be combined and in others they may not be required at all. An example of the latter would be if local residents hauled processed sludge from the treatment plant themselves. With the exception of short loading and unloading pipelines in combination with truck, barge or railroad transport, combined systems are rarely the best choice. The EPA publication Transport of Sewage Sludge (16) has a great deal of information on the planning of sludge transport systems.

E.1. PIPELINE

Headloss through a sludge pipeline is determined by the solids content of the sludge. Sludges greater than 10 percent can be pumped, but it may not be economically feasible. In general, pipeline transport is appropriate for sludges 4 percent or less (16). Liquid sludges with higher solids content can be diluted prior to transport through pipeline.

E.1.a. Route

Alternative pipeline routes must be evaluated. The terrain and distance between the treatment and disposal sites for various routes will influence the facility costs. Pipeline crossings such as highways, railroads and waterways may pose construction and maintenance problems. Subsurface considerations such as soil types and the locations of other utility lines must also be evaluated. Health considerations may prevent routing sludge pipelines in the close proximity of domestic water supply lines due to potential for cross-connections. The allowable distance will vary from a requirement that pipes not be installed in the same trench to requiring several feet of separation, depending on local regulations.

E.1.b. Size and Material

Preliminary sizing is required in the planning of pipelines. Table 5 gives pipeline sizes and flow rates for liquids. Typically, cement-lined cast iron or ductile iron pipe is used for sludge pipelines. Depending on local conditions, other materials may be more suitable.

TABLE 5. PIPELINE SIZE AND FLOW RATES

Pipeline size, in.	Sludge flow rate gpm @ 3 fps velocity	Pipeline capacity at 3 fps velocity for various daily hourly operating periods, mgd			
		4	8	12	20
4	120	0.03	0.06	0.09	0.14
6	280	0.06	0.13	0.20	0.34
8	500	0.11	0.24	0.36	0.60
10	800	0.18	0.38	0.58	0.96
12	1,100	0.25	0.53	0.79	1.32
14	1,400	0.35	0.67	1.01	1.68
16	2,000	0.45	0.96	1.44	2.40
18	2,500	0.57	1.20	1.80	3.00
20	3,000	0.70	1.44	2.16	3.60

E.1.c. Pumping Requirements

Pipeline pump station information is presented in Tables 6 and 7. The former gives the sludge pumping characteristics and the latter, the energy required for different operating times.

TABLE 6. PIPELINE SLUDGE PUMPING CHARACTERISTICS (16)

Pipeline size, in.	Flow, gpm	Hydraulic loss, ft/100 ft (C=90)	Approximate head available each pumping station, ft[1]	Pump efficiency, percent	Pumping station spacing-level terrain, ft
4	120	2.10	400[2]	45	19,048
6	280	1.40	450[2]	50	32,143
8	500	1.02	260	50	25,490
10	800	0.82	230	64	28,049
12	1,100	0.61	230	73	37,705
14	1,400	0.45	210	78	46,667
16	2,000	0.45	210[3]	70	46,667
18	2,500	0.39	225[3]	76	57,179
20	3,000	0.33	200[3]	78	60,606

[1] Based on non-clog, centrifugal, 1,780 rpm pumps.
[2] Pumps in series for additional head.
[3] Pumps in parallel for additional capacity.

TABLE 7. PIPELINE PUMPING STATION ENERGY (16)

Pipeline size, in.	Power, kw/1,000 gph ft head	Annual energy, kwh/ft head for daily hours of operation shown[1] Total station			
		4	8	12	20
4	0.0078	90	180	270	450
6	0.0070	-	378	567	944
8	0.0070	-	675	1,012	1,686
10	0.0055	0	843	1,265	2,108
12	0.0048	-	1,016	1,525	2,541
14	0.0045	-	1,211	1,816	3,027
16	0.0050	-	1,927	2,891	4,818
18	0.0046	-	2,219	3,328	5,547
20	0.0045	-	2,594	3,891	6,486

[1] Motor efficiency = 90%; pump efficiency = 80%; kw/11,000 gph-ft head =

$$\frac{0.00315}{(\text{pump eff})\ (\text{Motor eff})}$$

E.2. TRUCK

Truck transport is appropriate for liquid sludge with at least four percent solids and for dewatered sludge. Truck transport is normally feasible for one-way haul distances up to 80 miles.

E.2.a. Route and Travel Time

Travel time can be determined from the transport distance and traffic patterns. Average speeds of 25 mph for the first 20 miles and 35 mph for the remainder of the trip can be used to approximate the total travel time per truck load of sludge (16).

E.2.b. Size and Number of Trucks

The size and number of trucks can be determined from the type and quantity of sludge to be transported and the distance between the treatment and disposal sites. Local traffic regulations may govern the maximum size of trucks. Information for determining truck requirements are given in reference 16. For example a 10 mgd secondary treatment plant with a 20 mile haul distance, with trucks operating 8 hours a day 360 days per year, would require a total of 6 2,500 gallon trucks for liquid sludge or one 15 cubic yard truck for dewatered sludge.

E.2.c. Fuel Requirements

Unit fuel requirements for various types and sizes of sludge transport trucks are given in reference 16. The fuel use for the trucks in the previously cited example would be 4.5 miles per gallon.

E.2.d. Manpower Requirements

Manpower requirements for truck transport are given in reference 16 for liquid and dewatered sludges. These are based on the truck operating hours plus ten percent. For the 10 mgd example cited previously approximately 16,000 man-hours per year of truck operator time would be required for liquid sludge and 2,600 man-hours for dewatered sludge.

E.2.e. Loading, Unloading, and Vehicle Service Facilities

Auxiliary facilities for truck transport of sludge include elevated storage for dewatered sludge, loading equipment and unloading equipment. These should be planned in conjunction with the specific sludge processing systems they will serve. Other facilities may be necessary, depending on local conditions.

E.3. BARGE

Barging, although not a common method of sludge transport, is appropriate for liquid sludge with four to ten percent solids. Practical transport distances range from 20 to 320 miles and, of course, a suitable waterway must be available. Conceivably, barging could be combined with other methods of transport; however, it is generally preferable to use only one.

E.3.a. Route and Travel Time

The route for barging is confined to local waterways. It is unlikely that more than one, or possibly two, alternatives for barging sludge will be available.

The average speed of barges is about 4 mph although speeds of up to 7 mph can be achieved in open waterways. Transit times will be variable depending on traffic, draw bridges, locks, tides, currents, and other factors (16). For the 10 mgd plant cited in the earlier example, with a 80 mile barging distance approximately 2,600 hours of hauling time would be required for a 300,000 gallon barge, carrying 4 percent solids sludge.

E.3.b. Size and Number of Barges

The barge requirements vary with the type of sludge produced and the processing it receives prior to disposal. Barge requirements are given in reference 16. For the example cited above one 300,000 capacity barge would suffice, assuming storage at the plant is available while the barge is in transit.

E.3.c. Fuel Requirements

Fuel is required for operating the barge tow boat. Estimates for the tow boat size and fuel consumption are given in reference 16. In general, larger barges and tow boats are more efficient than smaller ones since fewer trips are needed to transport the same quantity of sludge. For the 300,000 gallon barge cited above, a tow boat of approximately 1,200 horsepower would be needed with a fuel consumption of 2,000 gallons per day.

E.3.d. Manpower Requirements

The annual labor requirements for barging operations are approximately twelve man-hours/barge load. Maintenance requirements are approximately 680 man-hours/year for plants up to 10 mgd, 1,640 man-hours/year for plants up to 100 mgd, and 2,400 man-hours/year for plants up to 500 mgd (16). Towed barges are generally unmanned during transit, therefore they have lower labor requirements than self-propelled barges.

E.3.e. Loading, Unloading, and Vehicle Service Facilities

Auxiliary facilities for barge transport include loading storage and equipment (pumps and a pipeline), a dock and control building, and unloading equipment (pipeline). Towing equipment servicing is the responsibility of the towing company unless self-propelled barges are used, in which case a shop will be needed.

E.3.f. Tow Tariffs

Tow charges are normally based on total tow boat billing times, including round trips and idling time. Tow tariffs are a function of tow boat size rather than barge size, so it is important to carefully match the two for maximum economy.

E.4. RAILROAD

Railroad transport is suitable for dewatered sludge and liquid sludge. Transport distances generally range from 20 to 320 miles. Railroad transport is not a common method of transporting sludge.

E.4.a. Route and Travel Time

Rail transport of sludge is constrained by the established rail lines and their routes. It is unlikely that more than one or two options would be available in a particular area. Transit times for transporting sludge by rail are usually on the order of several days, even for relatively short haul distances. The possibility of nuisance conditions arising because of putrifying sludge should be considered.

E.4.b. Size and Number of Cars

Tank cars used for rail transport of liquid sludge must be supplied by the shipper. These can be acquired from the manufacturer by purchase, lease, or contract. The demand requirements are given in reference 16. Hopper or side dump cars for dewatered sludge may be available from the railroad. A 20,000 gallon capacity tank car is the normal capacity. For a 10 mgd secondary plant producing 15 mg of sludge per year approximately 13 tank cars would be required of 2 loads per day. For dewatered sludge 50 cy hopper cars are used.

E.4.c. Fuel Requirements

While the fuel demands will be met by the rail company and will be included in the tariffs, the fuel consumed in transporting the sludge should be estimated for inclusion in the energy effectiveness analysis.

E.4.d. Manpower Requirements

Typical labor requirements for loading and unloading the railroad cars and for maintenance are given in reference 16. For the 10 mgd example cited above, O&M labor would be approximately 4,400 man-hours per year for liquid sludge and 3,600 man-hours per year for dewatered sludge.

E.4.e. Loading, Unloading, and Service Facilities

Railroad transport of sludge typically requires loading storage and equipment (pumps and piping for liquid sludge and hoppers for dewatered sludge), railroad sidings and unloading equipment. Unloading is ordinarily accomplished by gravity.

E.4.f. Tariffs

Costs for railroad transport vary widely and should be obtained as a result of close consultation with the carrier in question. In addition to distance and weight carried, the ownership of the cars, and regional variations will affect the tariffs. If the cars are to be leased, consideration must be given to leasing costs.

Section - F LAND APPLICATION

Land application includes those projects where sludge is applied to land for disposal, crop utilization, or reclamation of spoiled areas. Land application does not include trenching or landfill projects. Land application systems frequently involve utilization of sludge for agricultural production.

The local farm advisor, i.e. the state agricultural extension service or county agent, can be of tremendous help in the planning and evaluation of land application systems involving sludge application to cropland and should be consulted closely throughout the planning, design and operational stages of a land application system. A typical land application design calculation is shown in Appendix A.

F.1. PURPOSE

There are several possibilities for land application plans. In order to determine the proper techniques and loading rates, the land use purpose must be defined. The land may simply be a dedicated disposal site, utilized for agriculture, utilized for reclaiming marginal or disturbed soils or some combination of the above. Although annual application on parks or forests is not commonly practiced application prior to planting provides a good soil conditioner and a slow release nitrogen source. Discussions related to reclaiming marginal land apply to these special systems.

F.1.a. Dedicated Disposal

A site may be used for dedicated disposal with no crop grown. This should be a modification of a landfill system. Ultimate land use must be studied carefully before creating a dedicated land disposal area to avoid pollution of underlying groundwater or the buildup of excessive levels of heavy metals that could make the land unfit for agriculture.

F.1.b. Agricultural Utilization

Sludge applied for agricultural utilization can be of real benefit to farmers when applications are properly controlled. Agricultural use requires careful control of application rates to maximize the beneficial use of organic matter, nitrogen, phosphorus, and desired trace elements (those elements which are essential to plant growth but lacking in some soils, such as zinc and copper.) to insure contaminants are controlled within limits. Application rate determinations depend upon various factors such as soil type, crops to be grown, method of application and regulatory constraints.

Throughout this section and in later sections agricultural utilization at maximum rates on sites owned or controlled by the operating agency is emphasized. This does not preclude utilization on privately owned land or utilization at lower rates. It is common practice for farmers to use a combination of organic and chemical fertilizers. For example, sludge could be sold to the farmer and he may use it to meet half his nitrogen or phosphorus needs and supplement with chemical fertilizer to meet the rest of his needs. For more information refer to the section on off-site use by others.

F.1.c. Reclamation of Disturbed or Marginal Lands

Another purpose for utilizing sludge is reclaiming marginal or disturbed soils. These projects are similar to agricultural utilization projects in terms of goals and controls required. Higher application rates may be necessary to achieve the desired results.

F.1.d. Combinations

There may be several purposes for an area where sludge is applied. Agricultural operations or climatic constraints may result in an area being split such that some acreage is used for crops and some is used for dedicated land disposal. Reclamation sites may in some cases be converted to agricultural production areas.

F.2. EVALUATION OF POTENTIAL SITES

Site evaluation should include a review of all potential sites. This review must be through and timely since site acquisition or contractual agreements with private landowners can be time-consuming and must begin well in advance of facility construction. Site acquisition evaluation items should be reviewed on a short-term as well as long-term basis.

F.2.a. Geographical Location

The location of the site will affect economics of the land application system as well as the type system to be used. The site must be located so that surface water is not contaminated. The minimum distance between the site and surface water is a function of the application method to be used, the type of soil, crop, and slope of the land adjacent to the surface water. Intermittent or ephemeral streams should be considered as surface water systems. A major cost item in land application systems is transportation cost. This cost is a function of distance to transport and method of transportation. Also, in a given locale, some modes of transportation are more readily available than others. Condition and location of the nearest highways should be determined. In some instances road building or rebuilding may be required to bring roads up to standards required for heavy truck traffic. If river transportation systems or barges are available, then their proximity to proposed sites should be determined. In certain unusual situations a barge transportation system may be combined with another mode of transportation. For example, sludge may be barged from the plant to a transfer area and then trucked to the application area. Rail systems can often be found close to a treatment plant. Railroad transport availability at the site should be determined. As discussed above with barge systems, railroad transport may be considered in conjunction with other modes of transportation.

F.2.b. Compatibility with Land Use Plans

Regional planners or the planning commission should be consulted to determine land use plans for potential sites. The current use of the site should be determined by visiting each site. Variations during recent years should be noted, then the compatibility of the current use with the land application project should be determined. Regional plans, basic plans, and/or master plans should be consulted to determine the proposed future use of potential sites. Potential for variation in these plans should also be determined. Planners should be consulted for insights regarding these questions.

Current site zoning and adjacent area zoning and use should be determined. Actual zoning may be different from current use or from planned use. Adjacent land use may limit use of a site or cause restrictive conditions to be placed on use of a particular site. For example, if a nearby area is zoned for residential use, spraying of sludge may not be allowed. Area plans or zoning will reflect general planning intentions and can be changed with good justification. However, if specific development projects have been approved or have been initiated, then changes may not be accepted. Location of planned development projects should be determined. Selected sites should be flexible so that there is room for future expansion. This should be considered even for areas with growth controls since sludge characteristics and quantities per capita can change. Also, the additional space will allow room if application rates are lowered from those originally proposed.

F.2.c. Method of Land Acquisition

There are several means of acquiring the land for the application site. The best method will depend upon the local agency constraints, local regulatory agency requirements, and current ownership of the land.

Purchase of a site may take several years especially if the owners are not anxious to sell or are asking a very high price for the property. Condemnation proceedings may be required which cause further delay. Site purchase has the major benefit of allowing maximum flexibility to the agency. Since there are no arguments over operations with land owners and contract commitments are less. Purchase price, as well as potential acquisition problems, should be determined for potential sites.

Site lease agreements can be advantageous when a landowner does not want to permanently give up his property or wants to take advantage of improved soil characteristics resulting from the sludge addition. Lease agreements must be long-term in nature (10-20 years) to insure that the agency will have time to find alternative sites earlier than necessary. Lease agreements should specify acreage, use of land, and application procedures.

Some agencies may prefer to control the site but not have the responsibility for farming. This can be accomplished by purchasing the property and then leasing the site to a farmer, usually the previous owner. The farmer will then continue the farming operation. This approach provides the flexibility for the agency to change operators at a later date or to operate the system themselves.

Another approach to obtaining a site is to contract with a user. The advantages of this approach are that land acquisition problems are eliminated and the agency does not have to operate the farming system. Sludge application may be by the user or by the agency. The agency should have contracts with users with 10- to 20-year terms unless adequate acreage and interest in the use of sludge assure availability of alternate application sites.

Another possible alternative is a combination of land acquisition and lease agreements. Application rates for crop growth will be lower than rates for dedicated disposal without crops. With the combination approach, it may be advantageous for an agency to purchase adequate area for dedicated land disposal and still maintain leases with farmers to take sludge for soil conditioner. This provides maximum flexibility. The dedicated disposal area will provide the site for disposing of sludge when farming operations are not favorable for sludge application. Land leases are eligible for grant participation under certain conditions.

The land acquisition problem can be eliminated through direct sales of sludge to farmers. The farmer could be charged for sludge delivered (price per ton) and/or for sludge applied (price per acre). Sales should be through contract specifying quantities, application rates, areas to be used, monitoring required, and price.

F.3. STABILIZATION PROCESS

Under most circumstances before applying sludge to land the sludge should be stabilized to reduce pathogenic organisms and minimize odors and vector breeding. There are several alternative sludge stabilization processes discussed below. Some treatment plants may have more than one type of stabilization process. A major impact of variation in the sludge stabilization process used is the change in the resulting nutrient forms and concentrations. The potential for public access to a site is usually directly proportional to the degree of sludge stabilization that may be required. The processes discussed below are anaerobic digestion, aerobic digestion, composting, incineration, pasteurization, and chemical stabilization. This discussion describes the expected results. Detailed discussion of the process mechanisms is beyond the scope of this document.

Some stabilization occurs in storage lagoons. The stabilization rate and degree of stabilization are unpredictable. Storage lagoons are normally designed to be periodically drawn down. During this time, there would be no stabilization. The design can utilize several parallel lagoons to provide continuous storage for stabilization. The unpredictable lagoon performance and the potential for nuisance conditions with raw sludges are factors which must be thoroughly considered.

F.3.a. Anaerobic Digestion

Anaerobic digestion reduces pathogen concentrations significantly. Nitrogen concentrations can also be greatly impacted. Typical nutrient concentrations in anaerobically digested sludge are as follows:

COMPOSITION OF REPRESENTATIVE ANAEROBIC SEWAGE SLUDGES (17)

Component	Range*	Lb/Ton**
Total nitrogen	1 - 5	20 - 100
Ammonium nitrogen	1 - 3	20 - 60
Total phosphorus	1.5 - 3	30 - 60
Total potassium	0.27 - 0.8	4 - 16

* Percent of oven-dry solids
** Lb/ton dry sludge

F.3.b. Aerobic Digestion

Pathogen destruction by the aerobic digestion process is similar to that achieved by anaerobic digestion. Aerobic digestion has been used extensively at small activated sludge plants. Many extended aeration (including oxidation ditch) plants dispose of sludge without further digestion. This sludge will be similar to anaerobically digested sludge in terms of both nutrient content and degree of stabilization (measured by reduction in volatile solids, which averages 40-55 percent). Typical nutrient concentrations in aerobically digested sludge are as follows:

COMPOSITION OF REPRESENTATIVE AEROBIC SEWAGE SLUDGES (8)

Component	Range*	Lb/Ton**
Total nitrogen	3 - 6	60 - 120
Ammonium nitrogen	1 - 3	20 - 60
Nitrate nitrogen	0.5 - 1.5	10 - 30
Total phosphorus	1.1 - 5.5	22 - 110
Total potassium	0.8 - 1.1	16 - 22

* Percent of oven-dry solids
** Lb/ton dry sludge

F.3.c. Heat Treatment

Pasteurization is generally accomplished by a heat treatment conditioning process. Pathogens will be destroyed when the sludge is exposed to 159°F or 70°C heat for 30 to 60 minutes. Higher temperatures require less time for pathogen destruction. Nutrient concentrations in heat treated sludge are extremely variable. One source (18) reports the following:

NUTRIENT CONTENTS OF HEAT TREATED SLUDGE CONCENTRATION, %

Total N	2.8
NH_3-N	0.25
Total P	0.46
K	0.09

Generally, heat treatment processes reduce nitrogen contents while phosphorus and potassium content remains unchanged from raw sludge values. Heat treatment processes do not significantly reduce volatile organics or odors.

F.3.d. Chemical Stabilization

There are three main methods of chemical stabilization used at this time. They are stabilization by lime or lime and ferric chloride addition and by chlorine addition through the patented process "Purifax". All have been effective means of pathogen destruction but information regarding nutrient contents and the potential for generating toxic organics is limited. Ammonia levels will be reduced by either of these three processes. This reduction results from volatilization of ammonia at high pH values with lime treatment or the combination with chlorine to form chloramines. Lime stabilization can impact the phosphorus concentration (19) by combining some of the phosphorus with calcium to form calcium phosphate. A slight loss of total phosphorus is also likely.

F.4. AGRICULTURAL MANAGEMENT PLAN

Agricultural management is an essential part of planning a land application project. Selection of the crop(s) to be grown is necessary to determine loading rates and timing of sludge applications. Coupled with these considerations is planning the farming operation. Is the farming to be done by the agency or under contract? Long range planning should provide a flexible system.

F.4.a. Crops to be Grown, Rotation Plan, and Markets

The choice of crops to be grown depends primarily on local considerations and regulatory constraints. If locally grown crops are not suitable for sludge amended soils, then crops should be chosen which would be adaptable to local farming practices. Crop selection should be discussed with the local farm advisor. The crops chosen should be high nutrient users and have a cash value so sales can help offset operating costs. Field corn and forage crops are most frequently used. Sod farms are also excellent for utilizing sludge.

In many areas it may be advantageous to develop a crop rotation plan where the crop grown changes periodically. Crop rotation can be an important factor in the area of nutrient utilization and soil fertility. The crop rotation plan (if appropriate) should be developed before determining sludge application rates.

If cash sales are expected with crops grown on the land application site, then a market analysis should be completed. This analysis may be very brief if the crops grown are already common to the area. If a new crop(s) is to be brought into the area, the marketing analysis may be more complex since new markets would have to be developed. In either case some market analysis work is required.

F.4.b. Farming by Municipal Agency or Contract

If the agency or authority responsible for operating the sewage treatment plant will also be responsible for the farming operation, then plans must include hiring a staff and aquisition of equipment for farming. This staff should include equipment operators, maintenance staff and possibly additional laboratory technicians. The type of farm equipment is determined by the crop grown and sludge application techniques.

There are several options regarding contract farming. One would provide for all farming to be done by contract. Another option is to contract for harvesting, with the agency accomplishing all other farming operations. Other options include variations of responsibilities accomplished by contract and by the agency.

Application to private land would eliminate this responsibility with the municipality providing transport, application, both, or neither.

F.4.c. Long Range Plan

Long range planning should include plans to cover the management of application sites directly controlled by the municipality where recommended limitations for heavy metal additions are exceeded. These plans may include non-agricultural uses. For example, the application site may change from agricultural to forest land use.

F.5. NUTRIENT BALANCE

The major nutrients of interest in municipal sludge from an agricultural standpoint are macronutrients, or nitrogen, phosphorus, and potassium. Agricultural fertilizer requirements are expressed in terms of nitrogen compounds as nitrogen (%N), phosphorous compounds as phosphoric acid ($\%P_2O_5$) or phosphorus (%P), and potassium compounds as potassium oxide or potash (K_2O). Once the nutrient contents in the sludge are determined and crops selected, nutrient balances and corresponding application rates can be computed.

F.5.a. Nitrogen

Nitrogen is the most complex of the three nutrients. Plants utilize nitrogen in the ammonium and nitrate forms. Organic nitrogen in the soil must be converted or mineralized to the nitrate form. The mineralization rates are specific to individual areas and soil types. Nitrogen control is important since nitrates can create a potential problem if excessive levels are allowed to build up in groundwater supplies. Table 8 shows nitrogen requirements for various field crops. These requirements will vary at different locations and with different yields. Note that the values shown are pounds per acre utilized. This assumes that the crop is harvested and not plowed back into the soil.

F.5.a.(1) Forms of Nitrogen - Most sludges have nitrogen present in the ammonium and nitrate forms as well as organic nitrogen. Each nitrogen form must be addressed when planning a land application system. Nitrate nitrogen is readily usable by crops. If more nitrate is available than used by the crop, the excess may leach into groundwater supplies, potentially causing problems for the future use of this groundwater. Ammonia in sludge is found in the ammonium ion form. Ammonium is usable by crops. Planning for the correct application rate should take into account ammonia losses if sludge is applied and allowed to dry. If sludge is applied and allowed to remain on the surface, some of the ammonium will convert to ammonia, volatilize, and be lost to the atmosphere. These losses can amount to 20 to 70 percent depending on site specific conditions and length of time before the sludge is incorporated into the soil. The most complex nitrogen form (in terms of planning a land application system) is organic nitrogen. Plants cannot utilize organic nitrogen until it has converted or mineralized to the plant available forms.

F.5.a.(2) Mineralization Rate of Organic Nitrogen - Organic nitrogen is converted to usable forms at a variable rate, which depends on climate and soil type. The mineralization rate should be estimated based on experiences at sites with similar soil types in areas with similar climates. Usually, 15-25 percent

TABLE 8. PLANT NUTRIENT UTILIZATION BY VARIOUS CROPS (20)

Crop	Yield per acre	Pounds per acre		
		N	P_2O_5	K_2O
Field crops				
Barley	2 1/2 t	175	65	175
Corn (grain)	5 t	240	100	230
Corn (silage)	30 t	200	80	245
Cotton (lint)	1,500 lbs	210	90	150
Grain sorghum	4 t	250	80	200
Oats	3,200 lbs	115	40	145
Rice	7,000 lbs	110	60	170
Safflower	4,000 lbs	200	50	150
Soybeans	3,600 lbs	335	65	145
Sugar beets	30 t	275	85	550
Wheat	3 t	175	80	140
Vegetable crops				
Asparagus	3,000 lbs	95	50	120
Beans (snap)	10,000 lbs	175	35	200
Broccoli	18,000 lbs	80	30	75
Cabbage	35 t	230	65	250
Celery	75 t	280	165	750
Lettuce	20 t	95	30	200
Potatoes (Irish)	500 cwt	250	115	355
Squash	10 t	85	20	120
Sweet potatoes	12 t	115	45	230
Tomatoes	30 t	250	80	480
Fruit and nut crops				
Almonds (in shell)	3,000 lbs	200	75	250
Apples	15 t	100	45	180
Cantaloupes	30 t	190	60	340
Grapes	15 t	105	45	125
Oranges	30 t	120	40	175
Peaches	15 t	95	40	120
Pears	15 t	85	25	95
Prunes	15 t	90	30	130
Forage crops				
Alfalfa	8 t	450	80	480
Bromegrass	5 t	165	65	255
Clover-grass	6 t	300	90	360
Orchardgrass	6 t	300	100	375
Sorghum-sudan	8 t	325	125	475
Timothy	4 t	150	25	250
Vetch	7 t	390	105	320
Turf crops				
Bentgrass	2 1/2 t	225	80	160
Bermudagrass	4 t	225	40	160

of the organic nitrogen is converted the first year of application. Lesser amounts of the remaining organic nitrogen are converted during subsequent years. These amounts range from 5-10 percent the second year and from 2-3 percent in subsequent years (20, 21).

F.5.a.(3) Future Application Rate Adjustments for Mineralized Organic Nitrogen - Each year the application rate should be adjusted to account for mineralization of previous applications. This means that if sludge is being used on cropland and the nitrogen balance is critical, then either acreages must be increased or an alternative crop which uses higher nitrogen levels grown.

F.5.a.(4) Additional Nitrogen Needed for Crop (if any) - If application rates are limited (by heavy metals, for example), crop nitrogen requirement may not be met. There are two alternatives to solving this requirement. One is to switch to a crop with a lower nitrogen requirement. The other is to provide supplemental nitrogen. When needed supplemental nitrogen can be provided in several ways for each of many forms. The best method depends on local supplies and types of fertilization equipment available. Supplemental nitrogen would be provided only where crops have a high market value and are critical in terms of offsetting operating costs.

F.5.b. Phosphorus

For most crops phosphorus requirements are much lower than nitrogen requirements. Nitrogen and phosphorus contents in sludge are nearly the same. Therefore, application rates set for nitrogen utilization result in more phosphorus being added to the soil than will be used by the crop. While there are no established limits for phosphorus addition phytotoxic reactions can occur in plants if excessive phosphorus is applied. Records keeping should include phosphorus additions. If high levels of phosphorus are to be applied plans should be made for the future management of the application site if excessive phosphorus creates a problem. Actual phosphorus applications should be measured or expressed as P_2O_5. Crop utilization rates for phosphorus are shown on Table 8. These rates should be verified by the local farm advisor before they are used.

F.5.c. Potassium

Potassium concentrations in sludges are usually much lower than nitrogen and phosphorus concentrations. Crop potassium needs are generally higher than their phosphorus needs, and often equal to nitrogen requirements. Therefore, supplemental potassium is frequently required to insure maximum crop production. Typically it is supplied in the form of potash. Some areas having high background levels of potash in the soil may not require additions of potassium. Crop potassium utilization rates are shown on Table 8. When potash additions are required the supplemental requirements are determined by subtracting that added by the sludge and that amount available in the soil from the crop requirement.

F.6. HEAVY METAL LOADINGS

There has been much controversy about heavy metal applications and their impact on food chain crops. Essentially there are two criteria which minimize the potential for excessive metal uptake by crops. They are cation exchange capacity and maintenance of a soil pH greater than 6.5.

EPA, USDA, and a number of state agencies and land grant universities have issued guidance documents to assist project planners in determining sludge application rates. A number of these references cite guidelines or regulations which limit heavy metal additions to cropland through sludge application (22 to 29). The most current regulations are the EPA 40CFR257, "Criteria for Classification of Solid Waste Disposal Facilities and Practices" (29). Local, state, and federal requirements should be determined for the particular area at the time the project is planned.

F.6.a. Cation Exchange Capacity

The level of heavy metals in soils that begin to cause crop production problems can vary due to a number of soil factors, such as organic matter and clay content of the soil, which are reflected by the soil's cation exchange capacity (CEC). Suggested total amounts of heavy metals added to agricultural land as provided in EPA guidance documents published in 1978 are shown on Table 9. These suggested values were based upon maintaining the soil pH at greater than 6.5.

TABLE 9. SUGGESTED TOTAL AMOUNT OF SLUDGE METALS ADDED TO AGRICULTURAL LAND (30)

	Soil cation exchange capacity (meq/100 g)		
Metal	0 - 5	5 - 15	15
	Maximum Cumulative Amount of Metal (lb/acre)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	125	250	500
Cd	5	10	20

Determined by the pH 7 ammonium acetate procedure

F.6.b. Sludge and Soil pH

The combined sludge-soil pH should be maintained above 6.5 and when lower pH values are found, lime should be added to raise the pH. The metals concentrations are cumulative so previous additions must be considered.

F.6.c. Cadmium

Cadmium is generally the metal that causes the most concern for sludge applications to cropland. Both the soil and food chain crops can be adversely affected.

The US EPA interim final guidelines provide for two approaches to controlling land application of sludges containing cadmium. The first approach consists of three requirements. First, the pH of the sludge and soil mixture is 6.5 or greater at the time of application, except for sludge containing cadmium at concentrations of 2 mg/kg (dry weight) or less. Secondly, the annual application of cadmium from sludge does not exceed 0.5 kg/ha on land used for the production of tobacco, leafy vegetables, or root crops grown for human consumption. For other food chain crops, the annual cadmium application rate does not exceed:

Time period	Annual Cd Application Rate (kg/ha)
Present to June 30, 1984	2.0
July 1, 1984 to Dec. 31, 1986	1.25
Beginning Jan. 1, 1987	0.5

Thirdly, the cumulative application of cadmium from sludge does not exceed the following levels:

Soil Cation Exchange Capacity (meq/100 g)	Maximum Cumulative Application (kg/ha)	
	Background soil pH* <6.5	Background soil pH >6.5
<5	5	5
5-15	5	10
>15	5	20

* If the pH of the sludge and soil mixture is adjusted to and maintained at 6.5 or greater whenever food chain crops are grown then the levels of the next column are allowed.

The second approach consists of four requirements. These requirements are management oriented rather than providing specific cadmium levels. The first requirement is that the only food-chain crop grown is animal feed. Secondly, the pH of the sludge and soil mixture is 6.5 or greater and is maintained at this level during periods when food-chain crops are grown. Thirdly, there must be a facility operating plan which demonstrates how the animal feed will be distributed to preclude ingestion by humans. Measures required to safeguard against possible health hazards from cadmium entering the food chain should be included in the operating plan. The fourth requirement consists of notification of future property owners by a stipulation in land record or property deed that the property has received sludge at high cadmium application rates and that food chain crops should not be grown.

F.6.d. Nickel

Recommended maximum addition levels of nickel by sludge application to cropland are shown in Table 9 section F.6.a. Presently, toxicity of nickel to plants has only been observed in acid soils. If nickel concentrations are excessive then pH adjustment (upward) by lime addition should lessen the chances of plant damage.

F.6.e. Copper

Copper is useful to plants in small quantities but can be hazardous in excessive amounts to grazing animals (especially sheep). Recommended maximum addition levels by sludge application to cropland of copper are shown on Table 9.

F.6.f. Molybdenum

Very small amounts of molybdenum are necessary for crop growth. Plant damage is not likely but grazing cattle and other animals are susceptible to molybdenum toxicity. No limits have been established at this time. Areas near natural molybdenum deposits should be aware of this potential problem.

F.6.g. Zinc

Small amounts of zinc are necessary for crop growth. Zinc toxicity in plants is uncommon, occurring in acid soils. Sheep and cattle are susceptible to zinc toxicity at high zinc concentrations. If pH levels are maintained at or above 6.5, zinc toxicity should not be a problem.

F.6.h. Lead

Maximum recommended addition levels of lead by sludge application to cropland are shown in Table 9. Toxicity of lead to plants is likely only when the soil/sludge mixture pH is less than 5.5. Plant uptake of lead is minimized by increased soil/sludge pH, CEC, and available phosphorus (23).

F.7. SLUDGE APPLICATION RATES

The actual sludge application rate is determined based on the preceeding analysis. This rate is expressed in terms of annual dry weight, annual and daily wet weights. With the computed nitrogen additions and the known concentration contained in the sludge a maximum annual dry application is determined. In some instances this maximum will be limited by heavy metal limitations. The rate must not exceed the evaporation/percolation capability of the site unless provisions are made for control of surface runoff. To allow ease of acreage computations any variations in crop nutrient requirements, the total sludge application rate should be computed for each crop. Each application has a limiting factor. This factor should be determined early in the planning phase so that process changes affecting that factor can be determined. This can result in a major change in site size requirements. The maximum daily application with liquid sludge is usually determined by experience with a similar soil type.

As discussed previously annual applications are usually limited by the nitrogen balance. Nitrogen removal rates should be equal to or greater than application rates. If the sludge application rate has been set by balancing nitrogen removal with application and the maximum annual cadmium is exceeded with this rate, then the rate must be reduced to that allowable by the cadmium limitation. Phosphorus and heavy metals limitations discussed previously are generally maximum cumulative application limits.

F.8. SITE CONSIDERATIONS

Potential sites should be reviewed for size and flexibility for expansion or changing from one type of system to another. The following sections describe the considerations to be included in the facilities plan.

F.8.a. Site Size

The site size is a function of the net application area plus buffer area, future expansion, replacement area, and emergency sites for adverse weather conditions. The site size can be as much as twice the net application area depending on the specific circumstances.

F.8.a.(1) Application Area - The application area is determined as outlined in later sections. This is the land that receives sludge. This area is sized without buffer or replacement area considered and does not include standby disposal areas. These items are added as described below.

F.8.a.(2) Wet Weather Plan For Stockpile Storage or Alternative Disposal - The site area requirements should include space for stockpiling dewatered sludge, lagooning liquid sludge or an alternative disposal system unless provided at an alternative location. The alternative system might consist of a landfill, trench disposal, or a composting operation. When field conditions do not permit land application then the sludge can be stored or disposed of by an alternate method.

F.8.a.(3) Buffer Area - Some space may be required to separate the application area from neighboring areas. This space or buffer helps limit public access and minimizes the chances for nuisance conditions to develop. The space required is a function of the application method, prevailing wind velocity, and topography of the site. Application by spraying in a windy area in close proximity to residences might require a large buffer area. Sludge injection on level land should require very little buffer. The amounts vary between these two extremes.

F.8.a.(4) Expansion or Replacement Area - If the treatment plant capacity or treatment level increases, more sludge will be produced and must be managed. If this increased volume is to be applied to the land then more land will be required. An alternative to acquiring more land would be sizing the application area for future quantities expected in the next 20 years and apply at lower loading rates until the full capacity is reached. If application is accomplished on privately owned land then landowner committments should be made with increased quantities accounted for. When heavy metals limitations are reached on a particular site then an alternative application area must be found.

F.8.b. Compatibility With Future Expansion

Land application areas must be compatible with projected future expansions. The expansion may mean an increase in quantity due to increased population served by the plant, process modifications or changes in constituent levels. Any of these changes could cause a change in the area requirements or type of system to be used.

Changes in unit processes used can result in larger quantities of sludge, different chemical makeup of the sludge, or a sludge with a different physical nature or moisture content. Larger quantities of sludge or sludges of a different physical or chemical nature can result from a variation in operation of existing processes, replacement of a unit process with another type of process, or addition of new unit processes to meet more stringent discharge standards. Transportation costs are sensitive to the degree of dewatering. Variations in dewatering process operations may lower the volume to be hauled. This would also require adjustments at the application area. As communities grow there can often be significant changes in raw sewage constituent levels. This may be industrially related or related to tourism increases or changes in life styles. Changes in raw sewage constituent levels will result in a change in sludge constituent levels thus requiring adjustments in land application procedures or sludge application rates.

F.9. RUNOFF CONTROL

There are two sources of runoff. One is the liquid in the sludge and the other is precipitation falling on a sludge application site. Runoff control consists of containment and/or treatment of liquid from the site to prevent degradation of nearby surface streams. One of the best approaches to control of liquid in the sludge is rapid incorporation into the soil. Runoff from adjacent properties should be diverted around the application site. On-site containment of liquid from sludges or precipitation is normally provided by small impoundments placed at needed locations on the site. The contained liquids can be recycled for further treatment or can be reduced through evaporation and percolation or can be discharged after sufficient detention time to meet regulatory standards.

F.10. STORAGE

Storage is critical for time periods when application operations are not possible. These time periods may be several months due to severe cold weather conditions or they may be several days due to excessive precipitation. Storage requirements should include provisions for agricultural operations. If the types of crops grown preclude application for certain time periods, then storage will be required. Storage is usually provided by lagoons. Storage systems must be adequately sized and designed to minimize the possibility of nuisance conditions. The storage requirement will vary somewhat depending on application method. For example, dewatered sludge could be spread on frozen ground but liquid injection would not be feasible.

F.10.a. Capacity

Land requirements are based on the type of land application system. Agricultural utilization systems are sized based on application rate determinations described previously. Dedicated disposal systems are sized by operation constraints, such as weather limitations to operation, seasonal limits, and/or application equipment limitations.

F.10.b. Odor Control

Odor control is best achieved by adequate stabilization before storage. Odor control of partially stabilized sludge is extremely difficult. High dosages of chlorine or lime may help temporarily but may not be allowed by regulatory authorities. The best control method is backup stabilization processes and proper operation of stabilization systems.

Mixing aids in odor control by preventing layers from developing in deep storage systems which are subject to seasonal turnover which in turn causes odors. Mixing can help maintain aerobic conditions throughout. Aeration systems are an excellent means of providing odor control and additional stabilization of sludge. These systems must be very flexible since storage lagoon levels may fluctuate widely.

F.10.c. Drainage or Leachate Control

Storage lagoons should be lined in areas where groundwater supplies are threatened. More positive control can be provided by drainage ditches placed on the outside of berms around the lagoons. If lining is inadequate, and groundwater levels are high, the leachate may be captured by ditches for appropriate treatment.

F.11. MONITORING PROGRAM

Monitoring of land application systems is usually required by local, state or federal regulatory agencies. The monitoring program should meet these requirements and provide information feedback to assure proper system operation. The degree of monitoring will vary depending on regulatory agency requirements, type of crop grown, and sludge quality. Most land application monitoring programs are primarily concerned with three areas - subsurface water, soil, and sludge. In some instances monitoring of crop tissues may be included. These programs are developed to prevent potential health hazards and assure the production of high quality crops.

The entire monitoring program should be summarized in a tabulated form. This allows easy estimating of staff and laboratory facility requirements. This also provides a quick check on all monitoring results.

F.11.a. Monitoring Wells and Tests

Monitoring well requirements vary depending on local regulatory agency requirements and the depth to the water table. As a minimum wells should be 20 to 30 feet deep or to the first impermeable layer (if the layer is closer to the surface). The number of wells varies with site size and proximity of groundwater aquifers.

The tests normally taken at the wells are nitrate concentration, total coliform and fecal coliform counts and TDS concentrations. Nitrate concentrations should not exceed 10 mg/l. If background levels are found to increase significantly then changes should be made in application rates or cropping methods before the maximum allowable levels are reached. If they do reach maximum allowable levels then adjustments should be made to the application rates. If total coliforms, fecal coliforms or other measures are excessive operations should be stopped or sharply curtailed in the vicinity of the failing test until appropriate actions are taken to lower these levels. These tests should be run in accordance with procedures outlined in Standard Methods (9).

F.11.b. Soil Tests

The most common soil tests are nitrogen (all forms), phosphorus, potassium, pH and the heavy metals (Zn, Cn, Cd, Ni, Pb) listed previously. Significance of these tests has been discussed (23). The primary purpose of these tests is to check levels of each constituent in the soil as computed or predicted prior to sludge application. These tests should be run in accordance with Methods of Soil Analysis (31) or other standardized method.

F.11.c. Sludge Tests

The most common sludge tests required are the same as the soil tests plus percent solids and percent volatile solids. Their significance has been discussed in earlier paragraphs. These tests should be run in accordance with Standard Methods (9) and/or the Kansas State document (32).

F.11.d. Crop Tissue Analysis

Some regulatory agencies may require a crop analysis of crops grown on sludge amended soils. These tests are accomplished to determine plant uptake of heavy metals. Test procedures are found in the Kansas manual (32) and the "Official Methods of Analysis of the Association of Official Analytical Chemists, 1975 (33)

Section G - LANDFILL

Landfill is the planned burial of processed sludge at a site designated for this purpose. The sludge is applied to the land and buried by applying a layer of cover soil over it. It differs from land-spreading in that to be defined as a landfill, the soil cover should be thicker than the depth of the plow zone (34).

The following sections deal with various aspects of landfill planning. For more detailed information, the reviewer is referred to Process Design Manual; Municipal Sludge Landfills, EPA Technology Transfer, October 1978 (34).

G.1. METHOD

There are three basic methods of landfill disposal of sludge. Each has specific conditions for application which will be discussed.

G.1.a. Sludge Only Trench Fill

The sludge only trench method involves excavating subsurface trenches so that sludge may be buried entirely below the original ground surface. The soil resulting from the trenching operation is used as cover and not mixed with the sludge as a bulking agent. The sludge is dumped directly into the trench from the haul vehicle and generally covered the day it is received. Trench disposal is most appropriate for unstabilized or poorly stabilized sludges; the frequency of cover reduces the odors generally associated with these types of sludge.

G.1.a.(1) Narrow Trench - Narrow trenches are defined as having widths of less than 10 ft. This method is generally used for sludges with solids contents ranging from 15 to 28 percent. The application rate is 1,200 to 5,600 cu yd sludge/ac. Excavated material is usually used immediately to cover an adjacent sludge-filled trench. The soil cover thickness is between 3 and 4 ft.

The main advantage of the narrow trench method is that it is suitable for sludge with a relatively low solids content. The primary disadvantage of this method is that it is land-intensive because of the low application rates.

G.1.a.(2) Wide Trench - Wide trenches used for sludge disposal have widths of greater than 10 ft. Material which is excavated from the trenches is stockpiled neatly and used as cover for that trench. The method is suitable for sludges with solids contents of 20 percent or greater (34). The application rates range from 3,200 to 14,500 cu yd sludge/ac. The cover thickness depends on the type of equipment used at the landfill. For land-based equipment, 3 to 4 ft of cover is sufficient, however for sludge-based equipment, 4 to 5 ft of cover is required.

When compared to narrow trench operations, the wide trench method has two distinct advantages. It is less land-intensive, and liners can be used to contain sludge moisture, thus protecting the groundwater from contamination, thereby permitting deeper excavation. The primary disadvantage of the wide trench method is the need for a sludge with a solids content greater than 20 percent. However, if it is too high (greater than 32 percent) the sludge will not spread evenly.

G.1.b. Sludge Only Area Fill

With sludge only area fill, sludge is usually mixed with soil and placed above the original ground surface. It requires substantial amounts of imported soil, but is suitable in areas where the groundwater is shallow or bedrock prevails. This method is best suited for well stabilized sludge since daily cover is not usually provided. Liners can be used to protect the groundwater, and adequate drainage and run-off control are necessary to prevent contamination of nearby surface waters.

G.1.b.(1) Mound - Area fill mound applications are generally suitable for stabilized sludges with solids content greater than 20 percent. Soil is mixed with the sludge to provide bulk and stability before it is hauled to the filling area. At the filling area, the mixture is placed in 6 ft mounds and then covered with 3 to 5 ft of soil. A level area is required for disposal, however the use of earthen containment structures can permit disposal in hilly areas.

G.1.b.(2) Layer - Area fill layer applications are suitable for stabilized sludge with solids as low as 15 percent. Soil is mixed with the sludge, either at the filling area or at a special mixing area. The sludge/soil mixture is spread in even layers 0.5 to 3.0 ft thick. Interim cover is 0.5 to 1 ft thick and final cover 2 to 4 ft thick. Although level ground is preferred for this operation, it is possible to execute it on mildly sloping terrain.

G.1.b.(3) Diked Containment - To be suitable for diked containment, sludge must have a solids content of at least 20 percent. This method is suitable for either stabilized or unstabilized sludge. If the disposal site is level, earthen dikes are used on all four sides of the containment area. As an alternative to this, if the site is at the toe of a hill, only a partial dike will be required. Depending on the type of equipment being used, the interim cover will vary from 1 to 3 ft and the final cover from 3 to 5 ft. Although diked containment is an efficient disposal method from the point of view of land use, it does necessitate controls to prevent localized contamination from leachates.

G.1.c. Co-disposal With Refuse

When sludge is disposed of at a refuse landfill, it is termed co-disposal. There are distinct trade-offs in using this method rather than the sludge only methods. These are presented in detail in reference 34.

The two techniques for disposing of sludge in this manner are to mix it with the refuse or to mix it with soil.

G.1.c.(1) Sludge/Refuse Mixture - Stabilized and unstabilized sludges with a solids content of 3 percent or greater have been mixed with refuse and landfilled. The sludge is applied to the working face of the landfill on top of the refuse. The two are thoroughly mixed before being spread, compacted and covered. Interim cover is 0.5 to 1.0 ft and final cover, 2 ft. Application rates are low, generally ranging from 500 to 4,200 cu yd sludge/ac. The appropriate regulatory agencies should be consulted for their requirements on the disposal of unstabilized sludge by this method.

G.1.c.(2) Sludge/Soil Mixture- With this operation, sludge is mixed with soil and used as cover for a refuse landfill. The procedure requires stabilized sludge with at least 20 percent solids. One of the clear advantages of this method is that it promotes growth of vegetation areas without the use of fertilizer. It does, however, have the potential for causing odors since the sludge is not completely buried.

G.2. SITE SELECTION

Site selection is a critical process in the planning of a sludge landfill. It is directly related to the method of ultimate disposal. The site ultimately selected must be suitable for the type of sludge to be disposed of and situated in a convenient, yet unobtrusive, location.

The first step in selecting a landfill site is to establish the study area. This is most easily defined by determining a maximum economical haul distance. Unsuitable locations such as populated or clearly inaccessible areas, can be readily eliminated.

The site selection should be made by an iterative process in which numerous evaluation steps are made. The methodology for performing this analysis will vary from project to project. Numerical rating systems can be helpful in assessing the relative merits of prospective sites. A suggested procedure for assessment, screening and final site selection is presented in reference 34.

G.2.a. Identify Potential Sites

The number of potential sites will depend on the local conditions, the method of disposal, and the characteristics of the sludge being disposed of. Several distinct options should be considered in the evaluation.

Given a variety of potential landfill sites, it may be possible to eliminate certain of them early in the planning process. Considerations such as size, terrain, location, subsurface conditions and economics may be used in the initial screening process.

G.2.b. Public Participation Program

In the long run, active public participation will insure the ultimate acceptance of the landfill program. Public participation in the decision-making process should be initiated early in the planning stages to avoid unnecessary and costly delays.

The public participation program must be tailored to suit the particular project and the community which it is to serve. Public meetings, workshops, mass media publicity, etc. all serve to increase the public's understanding of the proposed project and provide the opportunity for people to contribute to the project.

Chapter 2 of reference 34 addresses the objectives, formation and execution of public participation programs for sludge landfill projects.

G.2.c. Technical Considerations

Numerous technical considerations must be reviewed as part of the final site selection process. These are briefly discussed below. Additional information regarding them can be found in reference 34.

G.2.c.(1) Haul Distance - The minimum distance over level terrain will be the most favorable haul condition. Transport through areas with low populations is preferable to transport through high density urban areas with congested traffic.

G.2.c.(2) Site Life and Size - The site life and size are directly related to the quantity and characteristics of the sludge and the method used for landfilling. Since the entire site cannot be used as fill area, both the gross area and the usable or fill area must be considered in determining the site size. Initially, the life of the site can be roughly estimated. As the landfill is used, the expected life should be re-evaluated to insure adequate capacity for future operations.

G.2.c.(3) Topography - In general, sludge landfilling is limited to sites with at least 1 percent slope and no more than 20 percent slope. Perfectly flat terrain tends to result in ponding while fill on steep slopes can erode.

G.2.c.(4) Surface and Groundwater - The location and extent of surface waters in the vicinity of the landfill can be a significant factor in the selection process. Existing surface waters and drainage near proposed sites should be mapped and their present and proposed uses outlined. Surface leachate control measures (collection and treatment) may be required as part of the landfill design.

Data on the groundwaters in the vicinity of potential landfill sites is essential in the selection process. Characteristics such as the depth to groundwater, the hydraulic gradient, the quality and use of the groundwater and the location of recharge zones are essential in determining the suitability of a landfill site. Such information should be collected during the facility planning stage and in advance of the final decision-making process.

G.2.c.(5) Soils and Geology - Soil plays an important role in sludge landfilling. The properties of the soil such as texture, structure, permeability, pH and cation exchange capacity, as well as the characteristics of its formation may influence the selection of the landfill site. The geology of possible landfill sites should be thoroughly examined to identify any faults, major fractures and joint sets. The possibility of aquifer contamination through irregular formations must be studied.

G.2.c.(6) Vegetation - The type and quantity of vegetation at and around the proposed landfill sites should be considered in the evaluation. Vegetation can serve as a natural buffer, reducing noise, odor and other nuisances. At the same time, clearing a site of timber or other heavy vegetation can add significantly to the initial project costs.

G.2.c.(7) Environmentally Sensitive Areas - There are presently five environmentally sensitive areas included in the "Classification Criteria for Solid Waste Disposal Facilities." (34, 29) These include wetlands, flood plains, permafrost areas, critical habitats of endangered species, and recharge zones of sole source aquifers. These should be avoided if at all possible when a landfill site is selected.

G.2.c.(8) Archaeological and Historical Significance - The archaeological and/ or historical significance of proposed sites should be determined early in the evaluation process. Any finds of significance at the selected site must be accommodated prior to final approval and construction.

G.2.c.(9) Site Access - Haul routes should utilize major highways, preferably those with a minimum of traffic during normal transport hours. Proposed routes should be studied to determine impacts on local use and the potential effects of possible accidents.

G.2.c.(10) Land Use - Zoning, restrictions and future development of potential sites should be considered in the selection process. Ideally, the sludge landfill should be located on land considered unsuitable for higher uses.

G.3. LEACHATE CONTROLS

It is essential that surface and groundwater supplies be protected from landfill leachate. The primary sources of leachate are the moisture in the sludge itself and storm water infiltration. Careful site selection is the first step in controlling leachate; there are also design features which can reduce the potential for contamination by leachates.

G.3.a. Adequate Surface Drainage

Providing adequate surface drainage is the first step in controlling leachate. Ideally, the landfill site should be on slightly sloping land so there is natural drainage. Storm water runoff should be diverted around the landfill.

G.3.b. Natural Attenuation

Contaminants in landfill leachate can naturally attenuate as they pass through the soil. The mechanisms by which this occurs and the potential for natural attenuation should be examined before artificial controls are planned or designed.

G.3.c. Containment

Clay soils can be used to provide an adequate barrier against leachate contamination of groundwaters. In some cases enough of this material will be available at the landfill site, while in other cases importation will be necessary. The use of soils as landfill liners or additives is site-specific and must be evaluated on an individual basis. Membrane liners may be useful at area fills and wide trench application areas. Although soil liners are preferable, polymeric and asphaltic materials have proven to be effective. The final selection of landfill liners will depend on on the specific characteristics of the site. If leachate containment is necessary at the landfill site, collection and treatment facilities must be provided. An underdrain or tile collection system is effective in routing the leachate to a sump or storage area. Several methods of treatment should be evaluated. Alternatives include discharge to a local sewage treatment plant, recycle through the landfill, evaporation of the leachate in collection ponds or on-site treatment. The ultimate method chosen will depend on the individual characteristics of the landfill method and site.

G.4 GAS CONTROL

Methane and carbon dioxide gas are products of the decomposition of organic matter in sludge. The gas production depends on the type and quantity of sludge, the type of landfill and the moisture present. Although both of these gases are odorless, methane can be explosive in confined areas. Gas controls are not considered necessary in isolated areas or if the landfill is isolated from inhabited areas. However, gas control measures will be necessary if the landfill is near any populated area.

Possible gas control measures include permeable and impermeable methods and gas extraction. Permeable methods involve installing a gravel-filled trench outside the fill area. Migrating gas is intercepted and vented to the atmosphere. A barrier of low permeability material can be used around the perimeter of the landfill to minimize lateral gas migration. A compacted clay layer about 2 ft thick is adequate in most cases. Synthetic materials may also be considered as possible barriers to migrating gas. Gas extraction, with or without methane recovery, has been initiated at some refuse landfills. It is not suitable for sludge landfills since they do not permit free movement of gas and are not ordinarily large enough to make such systems economically justifiable.

G.5. RUNOFF CONTROL

Factors of concern are similar to those discussed in F.9.

G.6. MONITORING

A preliminary monitoring schedule should be determined as part of the facility planning process. This should include, but not necessarily be limited to, staffing requirements, leachate, runoff, gas, and soil analyses, groundwater observation wells and general operational record keeping and reporting procedures.

Once the landfill is operating, the monitoring program should be revised to reflect changes in the original plan.

Section H - COMBUSTION

Combustion processes are not disposal methods but are volume and weight reduction methods. A residue (ash) will remain which must be disposed of by one of the three basic disposal techniques: land application, landfill, or off-site use by others. The weight and volume reduction can be of great value where land is scarce. In planning ultimate disposal methods for ashes, it must be kept in mind that their physical and chemical characteristics differ substantially from those of uncombusted sludge.

The efficiency of the sludge dewatering system (Table 10) is of key importance in determining the feasibility of the incineration process. As can be seen from Figure 3, the amount of heat (auxiliary fuel) required to sustain continuous combustion is dependent on the solids content of the sludge entering the incinerator.

TABLE 10. TYPICAL SLUDGE DEWATERING PERFORMANCES (7)

	Sludge Cake Solids (%)		
Type of sludge	Vacuum filter	Filter press	Bowl Centrifuge
Raw primary	25-38	45-50	23-35
Anaerobically digested primary	25-32	45-50	28-35
Primary & trickling filter humus	20-30	45-50	20-30
Primary & air activated	16-25	35-45	15-30
Primary & oxygen activated	20-28	35-45	-
Digested primary & air activated	14-22	45-50	15-30

H.1. METHOD

The basic methods of combusting sludge are described below.

H.1.a. Incineration

Incineration is the burning of the volatile fraction of the sludge in the presence of excess air. Incineration is a two-step process involving drying and combustion. Adequate fuel, air, time, temperature, and turbulence are necessary for a complete reaction. The drying step should not be confused with preliminary dewatering, which is usually by mechanical means and precedes the incineration process in most systems. When a sludge with a moisture content of about 65 percent is delivered to the incinerators, the heat required to evaporate the water nearly balances the available heat from combustion of the dry solids. Heat values of sludges are summarized in Table 4.

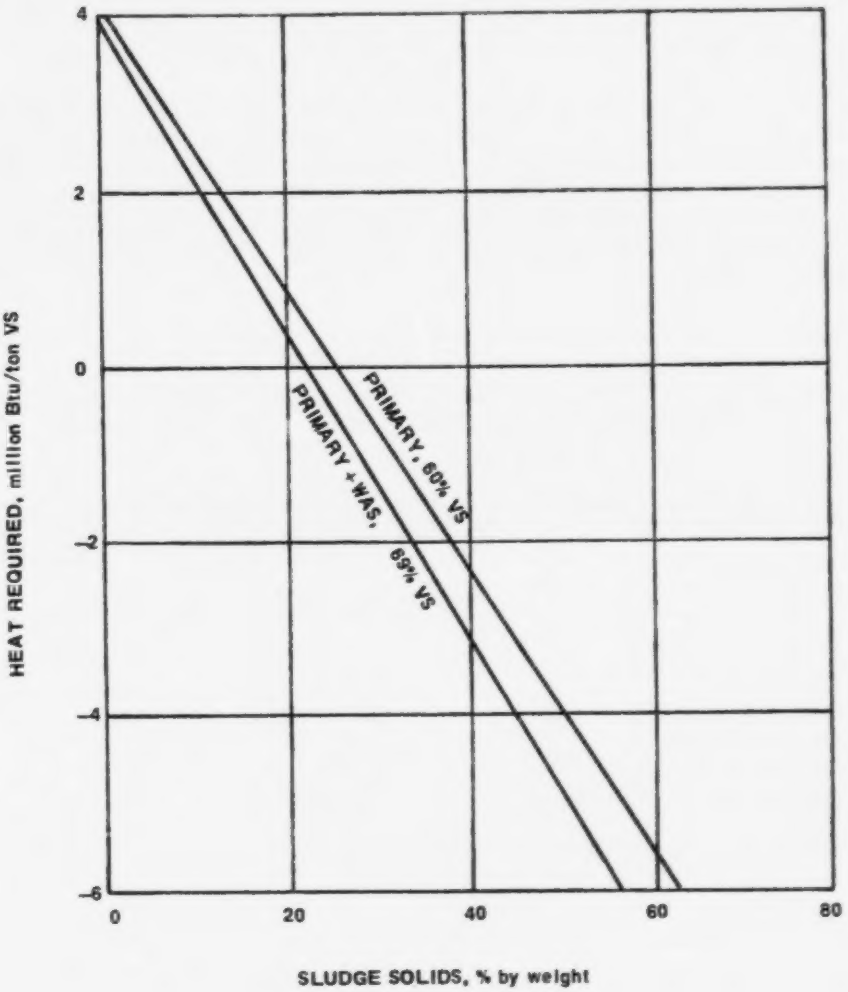


Figure 3. Theoretical heat required to sustain combustion of sludge.

Drying and combustion may be done in separate units or successively in the same unit. Manufacturers have developed diversified types of equipment such as the multiple hearth furnace and the fluidized bed incinerator.

H.1.a.(1) Multiple Hearth - A typical multiple hearth incinerator is shown in Figure 4 and consists of a circular steel shell surrounding a number of solid refractory hearths and a central rotating shaft to which rabble arms are attached. The operating capacity of these furnaces is related to the total area of the enclosed hearths. They are designed with diameters ranging from 54 inches to 25 feet, 9 inches, with four to eleven hearths. The upper hearths are the drying zone where moisture is evaporated and driven off as steam, the middle hearths are the combustion zone where the volatile portion of the sludge is burned, and the lower hearths are the ash-cooling zone.

Sludge enters the incinerator at the top and is raked by the rabble arms alternately outward and inward, as shown, to the entrance of the next hearth below. The rabble arms serve the multiple functions of moving the sludge through the furnace, forming furrows in the sludge layer on the hearth to maximize the exposed surface area, breaking up the sludge, and agitating the sludge to insure complete combustion.

Combustion air enters the incinerator at the bottom gaining heat from cooling ash in the cooling zone and from burning sludge in the combustion zone, and giving up heat to evaporate water from sludge in the drying zone.

H.1.a.(2) Fluidized Bed - A typical fluidized bed incinerator is shown in Figure 5. The fluidized bed incinerator is a vertical cylindrical vessel with a grid in the lower section to support a sandbed. Dewatered sludge is injected above the grid and combustion air flows upward at a pressure of 3.5 to 5.0 psig and fluidizes the mixture of hot sand and sludge. Supplemental fuel can be supplied by burners above or below the grid. In essence, the reactor is a single chamber unit where both moisture evaporation and combustion occur at 1,400 to 1,500°F in the sandbed. All the combustion gases pass through the 1,500°F combustion zone with residence times of several seconds. Ash is carried out the top with combustion exhaust and is removed by air pollution control devices. The heat reservoir provided by the sandbed enables reduced start-up times when the unit is shut down for relatively short periods (overnight).

H.1.a.(3) Cyclonic Reactors and Electric Incinerators - Horizontal cyclonic reactors are intended primarily for use at small wastewater treatment plants. They are usually available as skid-mounted packaged systems, requiring a minimum of field installation. High velocity air is preheated and introduced tangentially into a cylindrical combustion chamber, providing combustion air and heating the reactor walls. Sludge is sprayed radially toward the heated walls and is immediately caught up in the rapid cyclonic flow. Combustion takes place before sludge can adhere to the reactor walls. The ash is removed from the reactor by the cyclonic flow of air and gases.

The vertical cyclonic reactor is more suited to larger plants. The vertical cyclonic reactor has a rotating hearth and a single fixed plow. Preheated sludge enters the reactor at the outer edge and is plowed toward the center where ash is

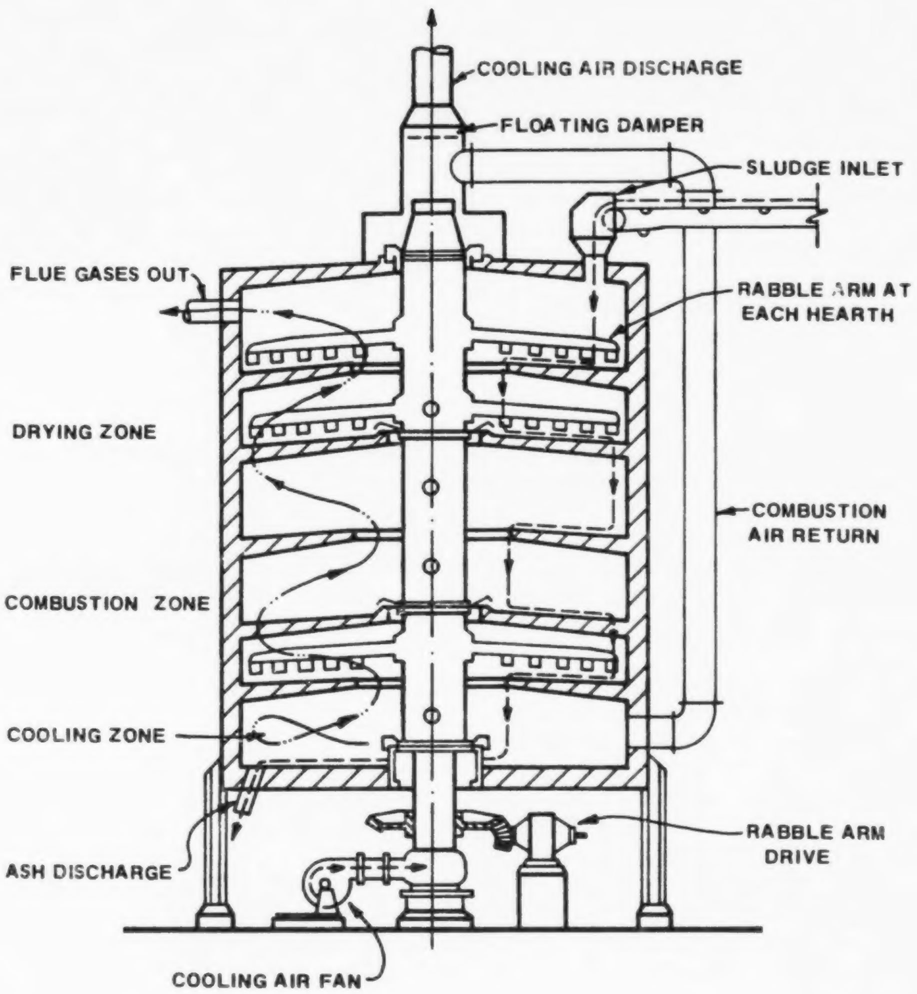

COOLING AIR DISCHARGE
FLOATING DAMPER
SLUDGE INLET
FLUE GASES OUT
RABBLE ARM AT EACH HEARTH
DRYING ZONE
COMBUSTION AIR RETURN
COMBUSTION ZONE
COOLING ZONE
RABBLE ARM DRIVE
ASH DISCHARGE
COOLING AIR FAN

Figure 4. Cross section of a typical multiple hearth incinerator.(7)

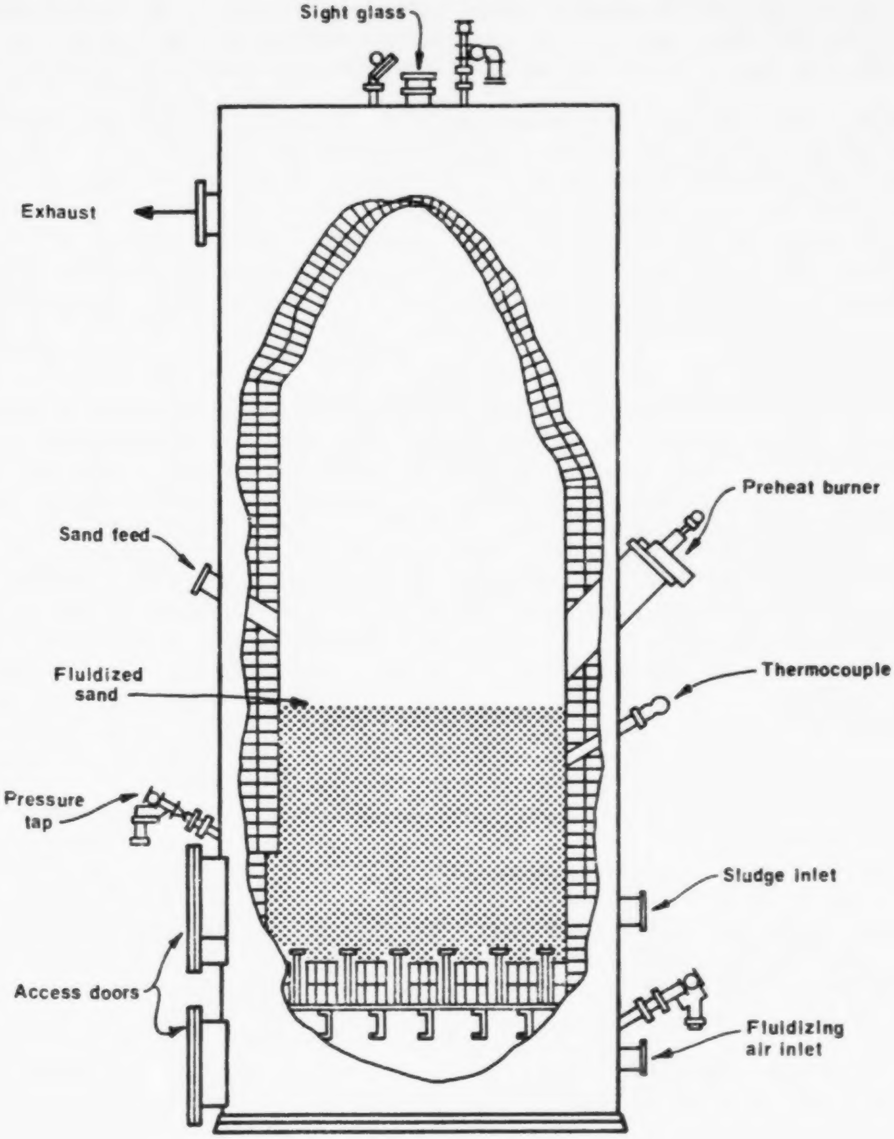

Sight glass
Exhaust
Preheat burner
Sand feed
Fluidized sand
Thermocouple
Pressure tap
Sludge inlet
Access doors
Fluidizing air inlet

Figure 5. Cross section of a fluid bed reactor. (7)

removed. Combustion air is introduced tangentially at high velocity, which results in a swirling motion over the top of the burning sludge. This provides needed turbulence and, together with sludge agitation by plowing, promotes complete combustion. Hot gases leave the cyclone through a top conical outlet in the center. Neither type of reactor is in common use in the U.S.

The electric incinerator uses infrared heat to raise sludge temperatures to the ignition point. Sludge is moved through the incinerator on a conveyor belt. It passes through a drying zone in which hot gases from the combustion zone, flowing countercurrent to the sludge, dry the sludge. The sludge then passes through a combustion zone where a battery of infrared lamps heat it to ignition temperatures. Combustion air enters in the combustion zone. Ash is discharged into a hopper at the end of the conveyor.

H.1.b. Pyrolysis

Pyrolysis is a process in which organic material is decomposed at high temperature in an oxygen-deficient environment. The action, causing an irreversible chemical change, produces three types of products: gas, tar (oil) and char (solid residue). Water vapor is also produced, usually in relatively large amounts depending on the initial moisture content of the materials being pyrolyzed. Residence time, temperature and pressure in the reactor are controlled to produce various combinations and compositions of the products. Two general types of pyrolysis process may be used. The first, true pyrolysis, involves applying all required heat externally to the reaction chamber. The other, sometimes called partial combustion and gasification or starved air combustion, involves the addition of small amount of air or oxygen directly into the reactor. The oxygen sustains combustion of a portion of the reactor contents which in turn produces the heat required to dry and pyrolyze the remainder of the contents.

Pyrolysis of municipal refuse and of sewage sludge has been considered as a means for ultimate disposal of wastes for several years (35, 36, 37, 38). The results of various studies and pilot programs indicate that if the moisture content of a sludge is below 70 to 75 percent, enough heat can be generated by combustion of the oil and gases produced from the pyrolysis of sludge for the process to be thermally sustaining. Pyrolysis of municipal refuse, and combinations of refuse and wastewater sludges will provide energy in excess of that required in the pyrolytic process (36, 37).

Laboratory, pilot and demonstration systems with wastewater sludges have been tested but no full-scale systems are in operation. Therefore, data presented must be considered preliminary. Pyrolysis systems are in the developmental stages and additional information will become available as research and development work and the operation of full-scale plants progresses.

Pyrolysis appears to have several advantages over incineration. For example, some pyrolysis processes can convert wastes to storable, transportable fuels such as fuel gas or oil while incineration only produces heat that must be converted to steam. Pyrolysis can give a 50 percent greater reduction in volume of residue over incineration and the residue is a more readily usable by-product. Air pollution is not as severe a problem in pyrolysis systems because the volume of stack gases and the quantity of particulates in the stack gases are less.

On the other hand, pyrolysis is still in the developmental stage and, with few exceptions, viable commercial systems are not readily available. Most of the pyrolytic fuel gases have relatively low heat values and the pyrolytic oil is corrosive, requiring it to be mixed with other fuel oil for best results.

The construction and operating costs for most pyrolysis systems are much more uncertain than for incineration. Reliable cost data for pyrolysis systems will not be available until significant operating experience is developed from the ongoing and planned demonstration projects.

H.1.b.(1) Multiple Hearth - Research and development work has been conducted on using multiple hearth furnaces, similar in design to conventional sludge incinerators, for pyrolysis of wastewater sludges mixed with municipal solid wastes (39). Shredded and classified solid wastes and dewatered sludge are fed to the furnace either in a mixture or separately, with the wetter sludge fed higher in the furnace. Recirculated hot shaft cooling air and supplemental outside combustion air are fed to the lower hearths to sustain partial combustion of the wastes circulating down through the furnace. Fuel gas produced through the pyrolysis reaction is then burned in a high temperature afterburner. The resulting heat can be used in a waste heat boiler to produce high pressure steam. It may also be possible to burn the fuel gases directly in a boiler. Char from the process is not used, but because it has some fuel value it may be usable as an industrial fuel.

The multiple hearth process offers the following advantages: (1) usable in much smaller plants than most other pyrolysis systems, (2) employs modifications of well developed sludge incineration equipment, (3) produces high temperature gases without raising temperatures in the solid phase to the slagging point, and (4) conversion from existing conventional sludge incineration systems is a relatively simple procedure. Disadvantages include: (1) fuel value of the char is not used, (2) high temperature fuel gases must be used on-site, and (3) incoming solid wastes must be well classified.

H.1.b.(2) Other Processes - There are several proprietary processes for pyrolysis of solid wastes, including sewage sludge. Several of these processes are listed below.

- Occidental Process - Occidental Research Corp.
- Purox - Union Carbide Corp.
- Torrax - Carborundum Environmental Systems, Inc.

H.1.c. Wet Air Oxidation

The wet air oxidation (WAO) process is based on the fact that any substance capable of burning can be oxidized in aqueous form at temperatures between 250°F and 700°F at elevated pressures. Wet air oxidation does not require preliminary dewatering or drying as required by conventional combustion processes. However, the oxidized ash must be separated from the water by vacuum filtration, centrifugation, or some other solids separation technique. Air pollution is minimized because the oxidation takes place in water at low temperatures and no flyash, dust, sulfur dioxide or nitrogen oxides are formed. A typical wet air oxidation process is shown in Figure 6. Sludge is ground to a controlled particle size and pumped to a pressure of 150-3,000 psig. Compressed air is added to the sludge, the mixture is brought to a temperature of about 675°F by heat exchange with treated sludge and direct steam injection, and then is processed (cooked) in the reactor at the desired temperature and pressure. The hot oxidized sludge is cooled by heat exchange with the incoming sludge. The treated sludge is settled from the supernatant before the dewatering step. Gases released at the separation step are passed through a catalytic afterburner at 650 to 750° or deodorized by other means. In some cases these gases have been returned through the diffused air system in the aeration basins for deodorization.

H.1.d. Co-Disposal with Solid Waste

Co-disposal of sludge with municipal solid waste has been proposed or practiced for most incineration and pyrolysis techniques. Relative to combustion process, co-disposal can take one of two forms:

- Combustion of the entire combined sludge and solid waste streams.
- Use of classified and shredded solid waste as a fuel to the extent required to make difficult-to-burn sludges autogenous.

H.2. MASS BALANCE

The calculation of the expected flow of mass into and out of the combustion process will aid in establishing its effectiveness and its economics. The mass balance calculation must be performed in conjunction with the energy balance discussed later in this section. The mass of inputs to the combustion process must equal the mass of outputs. (See Appendix C for sample calculation).

H.2.a. Inputs

- Dry Solids in Sludge - The mass of dry solids in sludge is usually expressed as tons per day and may be estimated directly or calculated from the wet sludge production and concentration.
- Moisture in Sludge - The mass of water in the sludge, usually expressed as tons per day, may be calculated from estimated or actual sludge production and concentration. The moisture will have a significant impact on the energy balance due to the energy required to heat and vaporize the water.
- Air - The quantity of air (or oxygen in some processes) introduced into the combustion process is usually expressed in tons per day or scfm. In combustion processes a certain theoretical (stoichiometric) oxygen

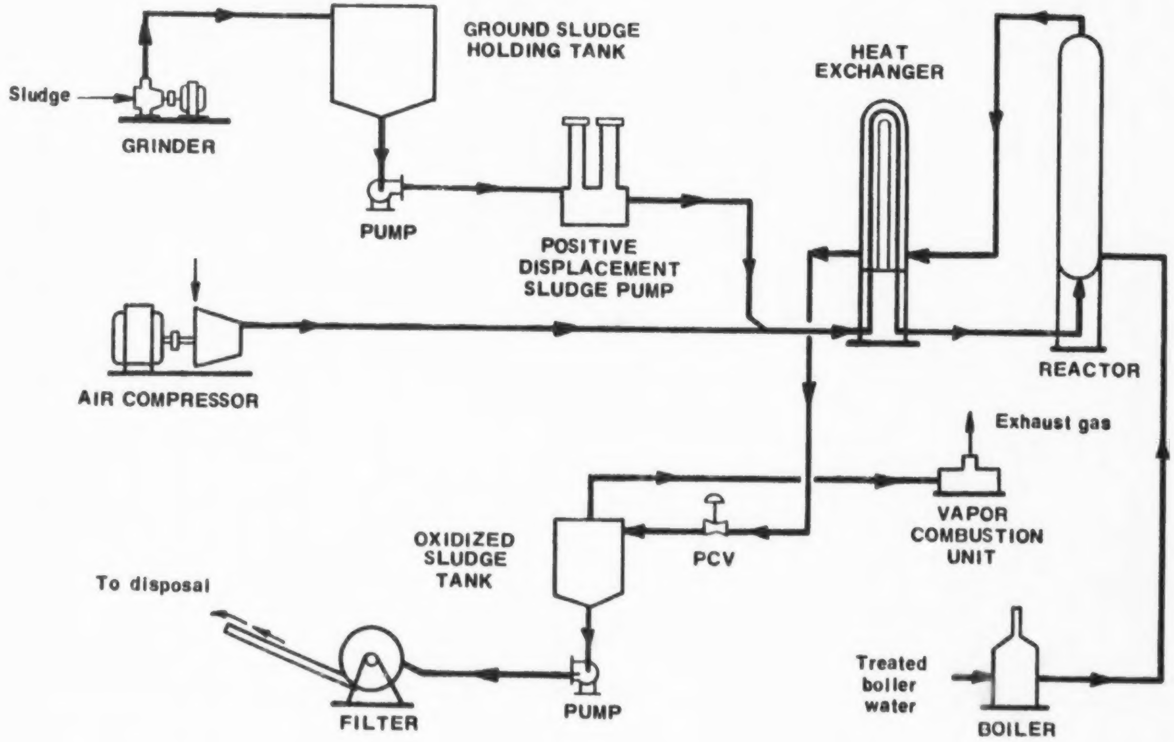

GROUND SLUDGE HOLDING TANK
Sludge
GRINDER
PUMP
POSITIVE DISPLACEMENT SLUDGE PUMP
HEAT EXCHANGER
REACTOR
AIR COMPRESSOR
Exhaust gas
VAPOR COMBUSTION UNIT
OXIDIZED SLUDGE TANK
PCV
To disposal
FILTER
PUMP
Treated boiler water
BOILER

Figure 6. Wet air oxidation system schematic. (7)

demand (THOD) must be met for complete combustion. In actual incinerators, however, it is not possible to completely combine the available oxygen with the combustible materials. A certain quantity of air in excess of the theoretical requirements must be provided to assure complete combustion. It must also be kept in mind that oxygen is not the only (or even the principle) constituent of air. The introduction of excess air should be minimized as it has the effect of reducing the burning temperature and increasing heat losses from the reactor. This will have a great effect on the energy balances as shown in Figure 7. The excess air requirements of the combustion process are empirically derived values which vary from 20 to 200 percent, depending on the installation. If a process has an approximate excess air requirement of 50 percent (typical for a fluidized bed reactor) and a theoretical oxygen demand of 200 tons/day, the actual air requirement would be:

$$q = (200 \text{ tons } O_2/\text{day})\left(1.5\ \frac{\text{total air}}{\text{theoretical air}}\right)/\left(0.23\ \frac{\text{mass of oxygen}}{\text{mass of air}}\right)$$

$$= 1{,}300 \text{ tons air/day}$$

or

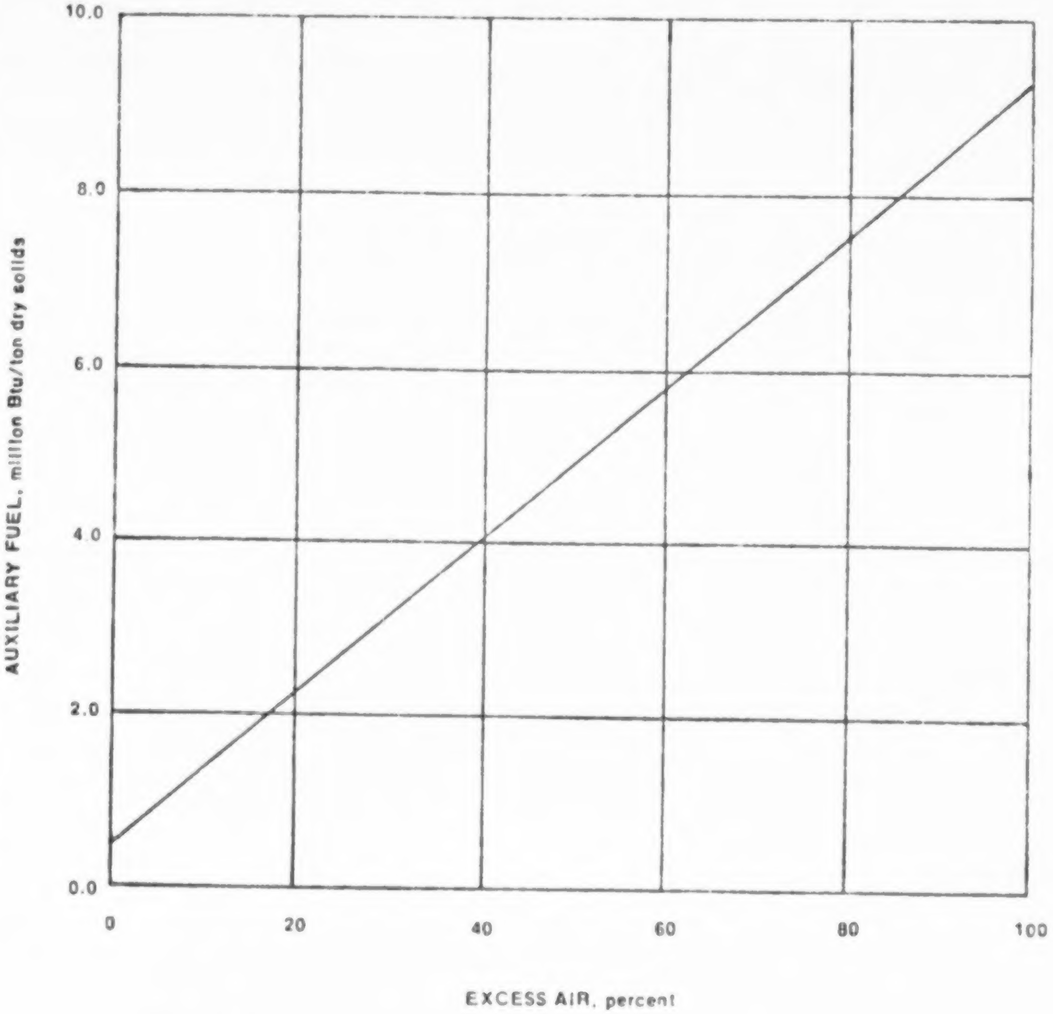
$$24{,}125 \text{ scfm air}$$

Pyrolysis processes are operated with deficient, rather than excess air. The calculation of air requirements would be the same as above except the ratio of actual to theoretical air would be less than one.

- Auxiliary Fuel - The mass of auxiliary fuel required will depend on the energy calculation and on the auxiliary fuel selected.
- Makeup Sand - Makeup sand will be required to replace sand lost in fluidized bed reactors.
- Steam - Steam is often injected into wet air oxidation reactors to begin or sustain the reaction.

H.2.b. Outputs

- Ash - Ash is the non-combustible, sterile residue of the incineration or wet air oxidation process.
- Combustible Gas - The principal product of pyrolysis is a combustible gas containing several gaseous hydrocarbons and other gases.
- Tar - Tar, or oil, is the combustible liquid residue of a pyrolysis process.
- Char - Char is the solid residue of the pyrolysis process.
- Water - Water is discharged from the process as water vapors in stack gases, in the liquid effluent of the wet air oxidation process, and as a contaminant in pyrolytic tar and combustible gas. The sources of



Assumptions:
Solids: 30%
Exhaust Temp: 1500°F
Volatiles: 70%

Figure 7. Impact of excess air on the amount of auxiliary fuel for sludge incineration.

water in the process discharge are, moisture in the incoming sludge, the combination of the hydrogen fraction of sludge solids and auxiliary fuel with oxygen, and steam supplied to the wet air oxidation process.

- Carbon Dioxide - Carbon dioxide is the result of the complete combustion of the carbon fraction of sludge solids and auxiliary fuel.
- Carbon Monoxide - Carbon monoxide is a toxic product of incomplete combustion. Its presence indicates insufficient excess air.
- Sulfur Dioxide - Sulfur dioxide is the combustion product of the sulfur fraction of the sludge solids and auxiliary fuel.
- Nitrogen - Nitrogen consists of the combustion product of the nitrogen fraction of the sludge solids and that portion of the theoretical combustion air which is not involved in combustion (approximately 79 percent).
- Sand - In fluidized bed reactors a certain portion of the bed sand is carried away with the fly ash.
- Excess Air - The excess air quantity discharged is the percent excess air supplied to the process.

H.3. ENERGY BALANCE

The energy balance, together with the mass balance, provides the basic data for determining the cost- and energy-effectiveness of the combustion process. The total input and output of the combustion process must be equal.

H.3.a. Inputs

- Solids Heat of Combustion - The solids heat of combustion is the energy released by the oxidation of the combustible fraction of the sludge.
- Auxiliary Fuel Heat of Combustion, Including Afterburner - The auxiliary fuel heat of combustion is the energy released by the burning of auxiliary fuels in the reactor, in an afterburner, or in a wet air oxidation steam generator.

H.3.b. Outputs

- Latent heat of moisture - That heat required to just vaporize the moisture with no effect on its temperature.
- The sensible heat of the stack gases - That heat which is required to raise those gases to respective temperatures at the point of exit from the air pollution control equipment.

- The sensible heat of the stack gases - That heat which is required to raise those gases to respective temperatures at the point of exit from the air pollution control equipment.

- Sensible heat of ash - Heat required to raise the ash or wet air oxidation effluent, from the temperature at the sludge inlet to the temperature at the ash, or effluent, outlet.

- Radiation and conduction losses - The energy lost to the surrounding air and objects by high temperature components of the combustion system.

- Shaft cooling air sensible heat: energy gained by the shaft cooling air in a multiple hearth unit in protecting the center shaft and rabble arms from heat damage.

- Recovered energy: that energy deliberately removed from the combustion process for other uses.

H.4. USE OF RECOVERED ENERGY

The practice of energy recovery in the combustion process can significantly affect the overall cost- and energy-effectiveness of a sludge management system. The selection of energy recovery systems must be based on the cost- and energy-effectiveness analyses, as in some instances the value of recovered energy may not justify the capital expenditure required to recover that energy.

There are several heat losses from the combustion process which can, by proper design, be intercepted so that a portion of the lost heat is recovered and put to use.

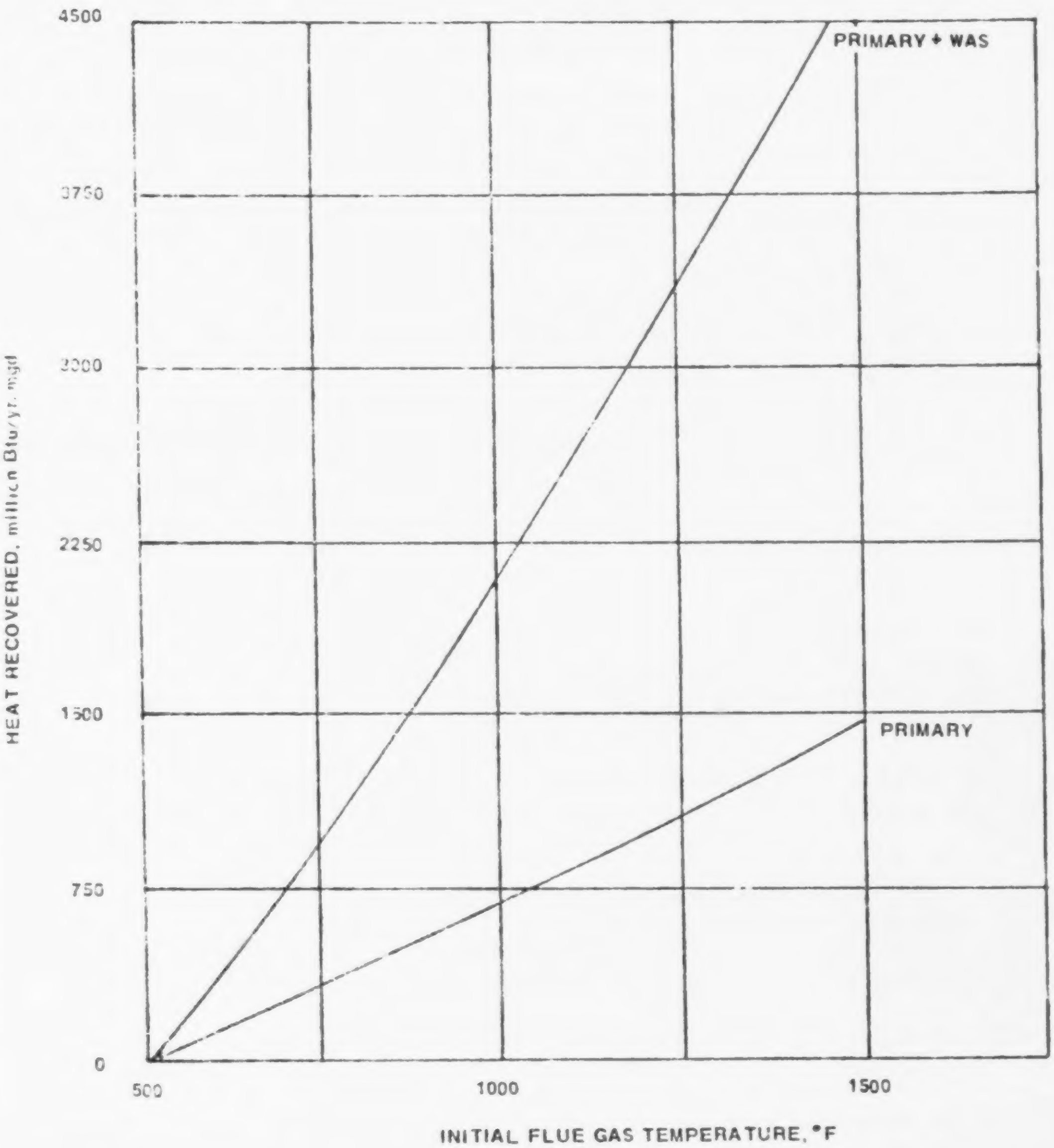
- Sensible heat of gases of combustion, excess air, and moisture
- Radiation and conduction
- Sensible heat of shaft cooling air
- Sensible heat of wet air oxidation effluent

In addition, if pyrolysis is practiced, the products of pyrolysis can be expected to have a fuel value apart from the heat recoverable from the process itself.

The exit gas sensible heat can be recovered by running the gases through a heat exchanger to produce steam, or hot water; or to heat a heat exchange fluid. The energy so recovered can then be used in any one of a number of ways. Figure 8 indicates the amount of energy recoverable from typical incinerator stack gases.

Radiation and conduction losses can be recovered by water jacketing the reactor and using the steam produced as an energy source on-site or for sale to others.

The sensible heat of multiple hearth furnace shaft cooling air is most often recovered by recycling it to the combustion process itself as preheated air.



Assumptions:
Final Stack Temp = 500° F
50% excess air

(To convert Btu to kwh: 1 kwh = 10,500 Btu)

Figure 8. Potential heat recovery from incineration of sludge

The sensible heat of multiple hearth furnace shaft cooling air is most often recovered by recycling it to the combustion process itself as preheated air.

The sensible heat of wet air oxidation effluent is normally recovered in the process itself by preheating incoming sludge. Other uses may be feasible and should be considered.

H.4.a. On-Site Use

Recovered energy from reduction processes can have a significant impact on the overall energy consumption, and therefore the cost-effectiveness of the entire wastewater and sludge treatment facility (40).

Combustion air preheating can significantly reduce auxiliary fuel requirements and can be practiced by cooling air return or by heat exchange between exhaust gases and combustion air. Steam, hot water, or heat exchange fluid could be used as a building heat source either directly or utilizing heat pumps. Additionally, the heat could be used as the heat input to absorption type cooling systems. Recovered heat can be used as the heat source for sludge thermal conditioning, improving the dewaterability of the sludge, which in turn improves its burning characteristics. Heat recovered from combustion processes can be used to heat anaerobic digesters, reducing the need for auxiliary fuel or eliminating the diversion to sludge heating of the more easily transported and stored methane gas. Steam generated by incinerator water jackets or by heat exchange with exhaust gases can be used to drive steam turbines. The steam turbines could generate electricity or serve as prime movers for process equipment. Pyrolytic gas may be burned in gas turbines for use in generating electricity or as prime movers for process equipment or as a fuel source for the pyrolysis reactor.

H.4.b. Off-Site Use

Under certain conditions, energy produced by the combustion process may have a market value which would justify its recovery. Facilities plans which anticipate energy sales should realistically evaluate the market potential as well as the value of the energy.

Combustible pyrolytic gas from sludge alone can be expected to have a heat content of 100-350 Btu/scf (35). By comparison, natural gas has a heat content of approximately 1000 Btu/scf. Co-pyrolysis with solid waste may produce higher heat values.

Pyrolytic tar, or oil, from sludge alone can be expected to have a heat content of 78,000-117,000 Btu/gal (35). No. 6 fuel oil has a heat content of 148,840 Btu/gal. It has a lower sulfur content than most oils but has a great deal of entrained moisture and is very corrosive. Co-pyrolysis with solid waste may produce higher heat values.

Pyrolytic char from sludge alone has a heat content of 1,000-2,400 Btu/lb (35). Pennsylvania anthracite coal has an approximate heat content of 13,900 Btu/lb. Char could be useful as a raw material for adsorbent manufacture. Co-pyrolysis with solid waste may produce higher heat values.

Steam may be the most easily marketable of the energy forms available as recovered energy. Many industrial processes use steam as an energy source. It is not as readily transportable as the other forms, however. Therefore, a suitable market must exist in the general vicinity of the combustion system. An additional problem is assuring adequate reliability of supply to the purchaser, as an unreliable supply of steam greatly diminishes its value.

Electricity is readily transportable and has the broadest potential market of the forms of recovered energy. Marketing the electricity to an electric utility may be feasible. The economics of electric power generation on the small scale possible at wastewater plants are, however, rarely favorable.

H.5. ASH DISPOSAL

Since the combustion process does not totally dispose of sludge, but merely reduces its volume and weight, ultimate disposal of the ash or residue must be considered.

H.5.a. Transport

Transport of ash is usually by truck or pipeline, as the greatly-reduced volumes usually preclude consideration of barges and rail. Incinerator ash can be pumped in a slurry from the combustion site to the disposal site but may require dewatering. Because of its finely divided nature, truck transport of dry ash can present problems if adequate dust control measures are not taken.

H.5.b. Dewatering

Wet air oxidation residual solids are easily dewatered for ultimate disposal on vacuum filters. When pumped in slurry, incinerator ash is usually dewatered in lagoons. Because of the relatively inert nature of ash, ash lagoons generally do not present the odor and fly problems that are typical of sludge lagoons.

H.5.c. Land Application

Ash and wet air oxidation residue have very little value as nitrogen sources, but their physical characteristics may make them useful as soil conditioners. In addition, they can have high phosphorus contents. All types of land application techniques are technically feasible, and several of the operational problems, such as disease vectors, pathogens, odors, and nitrate pollution of groundwater, are eliminated by the inert nature of the material.

H.5.d. Landfill

Landfilling of ash, including permanent lagooning, is the most common form of ultimate disposal. Many of the problems associated with sludge, such as odors, pathogens, disease vectors, gas production, and nitrate pollution of groundwater, are not present with ash. Cover is, therefore, less critical but must be maintained in order to minimize dust and leachate problems.

H.5.e. Off-Site Use by Others

Several off-site uses of combustion residues, other than the energy recovery discussed above, have been proposed or attempted. Incinerator ash has been tested as a soil amendment to improve the freeze-thaw characteristics of road subgrades, as a fine aggregate for building materials, as a soil conditioner, and as a quasi-fertilizer for its phosphorus content (41). Dewatered wet air oxidation residue has been tested with success as a soil conditioner and mulch and is valuable for its moisture-holding properties (42). Pyrolytic char has been suggested as a raw material for activated carbon manufacture (35).

H.6. AIR QUALITY CONTROL

National air pollution standards for discharges from municipal sludge incinerators have been promulgated which limit emissions of particulates (including visible emissions) from incinerators used to burn wastewater sludge as follows (43):

1. No more than 0.65 g/kg dry sludge input (1.30 lb/ton dry sludge input).
2. Less than 20 percent opacity.

For uncontrolled incineration of average municipal wastewater sludge, particulates will be about 33 pounds of particulates per ton of sludge burned in a multiple hearth (44), and about 45 pounds of particulates per ton of sludge burned in a fluid bed incinerator (45). Particulate collection efficiencies of 96 to 97 percent are required to meet the standard, based on the above uncontrolled emission rates. Impingement scrubbers, and Venturi scrubbers have demonstrated the capability to meet the particulate discharge requirement (46). Other potentially effective types include baffle, orifice and cyclone scrubbers. Wet scrubbing is normally required in conjunction with mechanical scrubbing. Most metals present in municipal sludges are converted to oxides which appear in the particulates removed by the scrubber or in the ash.

EPA has set a standard of 3,200 gms/day of mercury for discharge from a sewage sludge incinerator reference (47). Metal discharges should not present a limitation as properly designed and operated municipal systems have met all air pollution standards for metals.

Gaseous pollutants which could be released by sludge incineration are hydrogen chloride, sulfur dioxide, oxides of nitrogen, and carbon monoxide. Carbon monoxide is no threat if the incinerator is properly designed and operated. Hydrogen chloride, which would be generated by decomposition of certain plastics, is not a significant problem at concentrations currently observed. Consideration of the possibility of SO_2 and NO_x pollution is aided by examination of the sulfur and nitrogen content of sludges. Sulfur content is relatively low in most sludges. In addition, much of this sulfur is in the form of sulfate, which originated in the wastewater. Sulfur dioxide is not expected to be a serious problem. NO_x production from sludge incineration should be less than 100 ppm from a properly operated incinerator. Considering this low concentration, the production of oxides of nitrogen will probably not limit the use of incineration for disposing of sludge in most cases.

Toxic substances could be discharged from the organic substances such as pesticides and PCB's - in the sludge. However, tests (48) have shown that total destruction of PCB's was possible when oxidized in combination with sewage sludge and with exhaust gas temperatures of 1100°F. Ninety-five percent destruction of PCB's was achieved in a multiple hearth furnace with no afterburning at exhaust temperatures of 700°F.

In all cases involving designated nonattainment areas the local regulatory agency offset policy should be considered.

The principal methods of air pollution control are:

- Venturi scrubbers
- Afterburners
- Electrostatic precipitators

H.7. FUEL

There are a number of variables which influence the amount of fuel required and the resulting cost for sludge incineration. Principal variables are the solids and volatile solids content of the sludge. Their effect on the amount of heat required for incineration is shown by Figure 3.

The principal sources of auxiliary fuel are:

- Natural gas
- Oil
- Refuse derived fuel
- Powdered coal (49)

Section I - SLUDGE FOR OFF-SITE USE BY OTHERS

The use of sludge as a fertilizer and soil conditioner under the direct control of the wastewater treatment agency is discussed under the land application section of this document. This section deals with sludge that is processed in-plant and then given or sold to the public or private entrepreneurs. The processing produces a dry, marketable product that is safe for limited applications as a soil conditioner or fertilizer. This disposal scheme has several advantages over other methods:

- Sludge is utilized rather than discarded
- Land purchase or lease requirements are reduced
- Part of the cost of processing may be recoverable through product sale
- Potential adverse environmental impacts are spread over a wider area, minimizing their effect

The chief disadvantage to off-site use by others is the loss of agency control over sludges which may be unsafe if improperly used.

Sludge factors which affect acceptability and safety include:

- Degree of stabilization
- Heavy metals content
- Toxic organic compound content
- Pathogen content

The level of agricultural or horticultural sophistication of the intended users should be kept in mind. Sludges which could be safely sold to professional nurserymen for use on ornamental plants only may not be suitable for sale in bagged form to the general public. Local, state and federal agency regulations should be consulted to determine if any restrictions on marketing exist.

I.1. MARKET ANALYSIS

A key step in evaluating potential off-site use alternatives is analyzing the market for the product. This includes identifying the potential market, analyzing the capacity of the market to absorb the product, determining the realistic market value of the product, identifying the most desirable packaging for the product, and establishing a brand name for the product. Data for the market analysis can be obtained by telephone or mail surveys of individuals, possibly sent with their utility bills, and telephone or personal interviews with possible large users, wholesalers, and processors. The EPA publication User Acceptance of Wastewater Sludge Compost (50) contains considerable information on the market for processed sewage sludge.

I.1.a. Intended Market

The first step in the market analysis is identifying the potential market and market restrictions for the product. The potential users can be divided into three broad categories:

- Government agencies
- Wholesalers and processors
- Private users

I.1.a.(1) Government Agencies - Government agencies offer what is potentially the most advantageous of possible markets. Where sludge is used by government agencies it is usually possible for the wastewater treatment agency to retain a high degree of control over the final use of the product. There will usually, however, be no direct cash return for the product, but an economic benefit may be derived by the reduction in the cost of fertilizer use. The market analysis should consider agencies at the local, state and federal level.

Highway departments often use fertilizers and soil amendments for plantings alongside roadways. These plantings are not food chain crops and may present a potential use for sludge not safe for use on food chain crops due to heavy metal content. Care must be taken in sludge application, however, to avoid runoff. The same advantages would apply to municipal recreation facilities such as parks and golf courses, reforestation and tree or turf farming.

I.1.a.(2) Wholesalers and Processors - Sewage sludge has been sold to fertilizer wholesalers for distribution through the normal fertilizer and soil conditioner market place. Sludge has also been sold or given to fertilizer manufacturers for use as a raw material in the manufacture of commercial fertilizers. These options present a problem in that the end use of the sludge is nearly impossible to control, limiting the market to those sludges which are safe for human food chain crops.

I.1.a.(3) Private Users - The sale or distribution of sludge to private users has also been utilized, especially by smaller communities when the sludge is safe for food chain crops. Chief obstacles to be overcome include assuring the quality of the sludge and the lack of control over the use of the sludge. While some control can be exercised over large private users, it is virtually impossible to control the use of sludge or sludge products by individuals. This is a major factor being addressed by various agencies in updated guidance and regulations.

Nurseries of all types have the potential of using sewage sludge. In particular, sludge would be useful in cultivating non-food chain ornamental plants for sale, silviculture, and sod production. Agricultural uses of sludge are numerous including all types of above ground crops. The use of most sludges on root crops and leafy vegetables is generally not recommended (21). Sludge is also used in many communities by home gardeners. This market is the most difficult to control and requires the utmost care in assuring sludge quality and safe use. Sewage sludges are most applicable to lawn and ornamental plant cultivation.

I.1.b. Capacity of Market to Absorb Product

The capacity of the intended market or markets to utilize the entire production of the sludge management systems must be evaluated. In highly urbanized areas it may not be possible to market the entire sludge production within an economical transportation distance.

I.1.c. Market Value of Product

The potential market value of the product must be determined. The market value is best approximated by the sale price of similar fertilizers and soil conditioners similarly marketed. There are several complex factors which also enter into the determination of the actual market value, such as public acceptance, but their effects are difficult to quantify. Their effects can be explored through surveys of public acceptance.

I.1.d. Packaging Requirements

Packaging and product delivery system requirements will vary with the intended market. Large users will generally prefer delivery in bulk while smaller users, such as individuals, may prefer a bagged product. In addition, a determination as to whether the product must be delivered to the user or if the user is willing to pick up the sludge.

It has been found (50) that affixing a brand name to the sludge product greatly enhances its marketability. Some typical brand names in use are:

- Nu-Earth (Chicago, IL)
- Hou-Actinite (Houston, TX)
- Zitrohumus (Los Angeles, CA)
- Philorganic (Philadelphia, PA)
- Biogrow (Salem, OR)
- Metrogrow (Madison, WI)
- Milorganite (Milwaukee, WI)
- Largrow (Largo, FL)

I.2. PROCESSING METHOD

Sludge suitable for use off-site by others is usually processed by drying or composting.

I.2.a. Drying

Well stabilized sludges may be suitable for use off-site after drying.

I.2.a.(1) Drying Beds - The most widely used dewatering method in the United States is drying of the sludge on open or covered sandbeds. They are especially popular at small plants. Sandbeds possess the advantage of needing little operator skill. Air drying is normally restricted to well digested sludge, because raw sludge is sometimes odorous, attracts insects, and does not dry satisfactorily when applied at reasonable depths. The design and use of drying beds are affected by many parameters. They include weather conditions, sludge characteristics, land values and proximity of residences, and use of sludge conditioning aids.

Drying times typically range from 4 to 12 weeks, depending upon the weather. Especially adverse weather can result in drying times as long as 6 months (51).

I.2.a.(2) Drying Lagoons - Lagoon drying is a low cost, simple system for sludge dewatering that has been commonly used in the United States. Sludge is removed periodically and the lagoon refilled. Sludge is stabilized to reduce odor problems prior to dewatering in a drying lagoon.

Most design factors include climate, subsoil permeability, lagoon depth, loading rates, and sludge characteristics.

Sludge will generally not dewater in any reasonable period of time to the point that it can be lifted by a fork except in an extremely hot, arid climate. If sludge is placed in depths of 15 inches or less, it may be removed with a front-end loader in 3 to 5 months. When sludge is to be used for soil conditioning, it may be desirable to stockpile it for added drying before use.

I.2.a.(3) Heat Drying - Heat drying raises the temperature of the incoming sludge to 212°F (100°C) to remove moisture which reduces total volume, yet retains the nutrient properties of the sludge. The end product is odor free, contains no pathogenic organisms, and contains soil nutrients. Sludge has been heat dried in flash drying equipment and rotary kilns. Heat dried sludge requires more energy per unit of nutrient produced when compared to commercial fertilizers.

I.2.a.(3) (a) Flash Drying - Flash drying is the instantaneous removal of moisture from solids by introducing them into a hot gas stream. There are two basic flash drying systems: cage mill dryers and jet mill dryers.

A flow diagram of the cage mill process is shown in Figure 9. The system is based on three distinct cycles which can be combined in different arrangements. The first cycle is the flash drying cycle, where wet filter cake is blended with some previously dried sludge in a mixer to improve pneumatic conveyance. The blended sludge and the hot gases from the furnace at 1,300°F are mixed ahead of the cage mill and flashing of the water vapor begins. The cage mill mechanically agitates the mixture of sludge and gas and the drying is virtually complete by the time the sludge leaves the cage mill. The sludge, at this stage, is at a moisture content of 8 to 10 percent and dry sludge is separated from the spent drying gases in a cyclone. The dried sludge can be sent either to fertilizer storage or to the furnace for incineration. See F.3.c.(1), Part II for more detail.

I.2.a.(3) (b) Rotary Kiln Dryer - The rotary kiln is a cylindrical steel shell mounted with its axis at a slight slope from the horizontal as shown in Figure 10. Dewatered sludge is fed continuously into the upper end. A portion of the dried sludge is mixed with the feed sludge to reduce moisture and disperse the cake. Vanes pick up the material, then steadily spill it off in the form of a thin sheet of falling particles as the dryer rotates. This action is intended to provide contact between sludge and gases to promote rapid drying. The dried sludge from such a unit will consist of varied sizes of particles that may require grinding before use. Deodorization of the exhaust gases by after burning at approximately 1,200° to 1,400°F (650° to 760°C) is necessary if odors are to be avoided. Also, scrubbers must be used to remove particulates from the exhaust gases.

I.2.b. Composting

Composting is a method of biological oxidation of organic matter in sludge by thermophilic organisms. Composting, properly carried out, will destroy objectionable odor producing elements of sludge, destroy or reduce disease organisms because of elevated temperature, and produce an aesthetic and useful organic product.

Composting systems generally fall into three categories: (a) pile, (b) windrow, and (c) mechanized or enclosed systems. The pile (static aerated pile) and windrow systems have been used almost exclusively in composting sewage sludge because of their low cost and demonstrated performance. Mechanized or enclosed systems have not been used to any extent recently in the U.S. on sewage sludge. The general composting method is very similar for all processes. The dewatered sludge (typically 20 percent solids) is delivered to the site and is usually mixed with a bulking agent. The purpose of the bulking agent is to increase the porosity of the sludge to assure aerobic conditions during composting. If the composting material is too dense or wet it may become anaerobic thus producing odors or if it is too porous the temperature of the material will remain low. Low temperatures will delay the completion of composting and reduce the kill of disease organisms.

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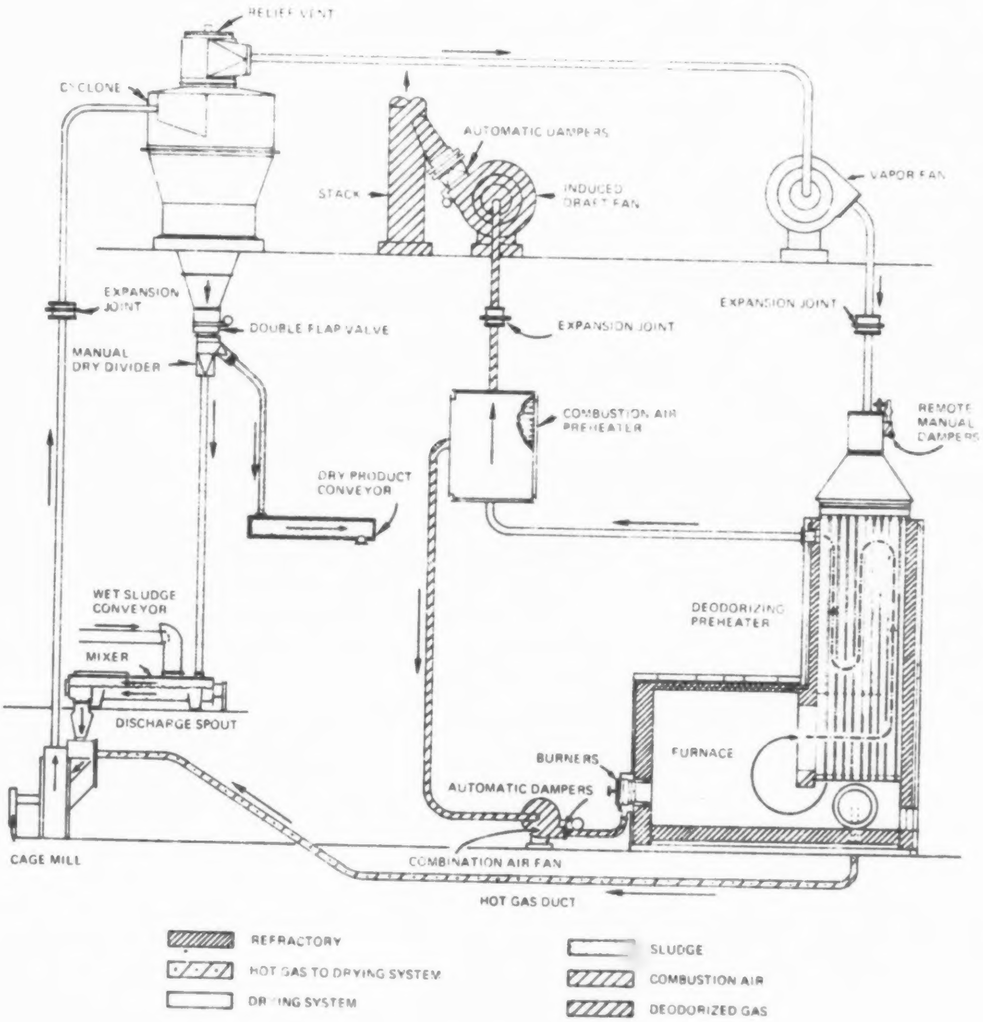
RELIEF VENT
CYCLONE
AUTOMATIC DAMPERS
STACK
INDUCED DRAFT FAN
VAPOR FAN
EXPANSION JOINT
DOUBLE FLAP VALVE
MANUAL DRY DIVIDER
EXPANSION JOINT
EXPANSION JOINT
COMBUSTION AIR PREHEATER
REMOTE MANUAL DAMPERS
DRY PRODUCT CONVEYOR
WET SLUDGE CONVEYOR
DEODORIZING PREHEATER
MIXER
DISCHARGE SPOUT
BURNERS
FURNACE
AUTOMATIC DAMPERS
CAGE MILL
COMBINATION AIR FAN
HOT GAS DUCT
REFRACTORY
HOT GAS TO DRYING SYSTEM
DRYING SYSTEM
SLUDGE
COMBUSTION AIR
DEODORIZED GAS

Figure 9. Cage mill flash dryer system. (52)

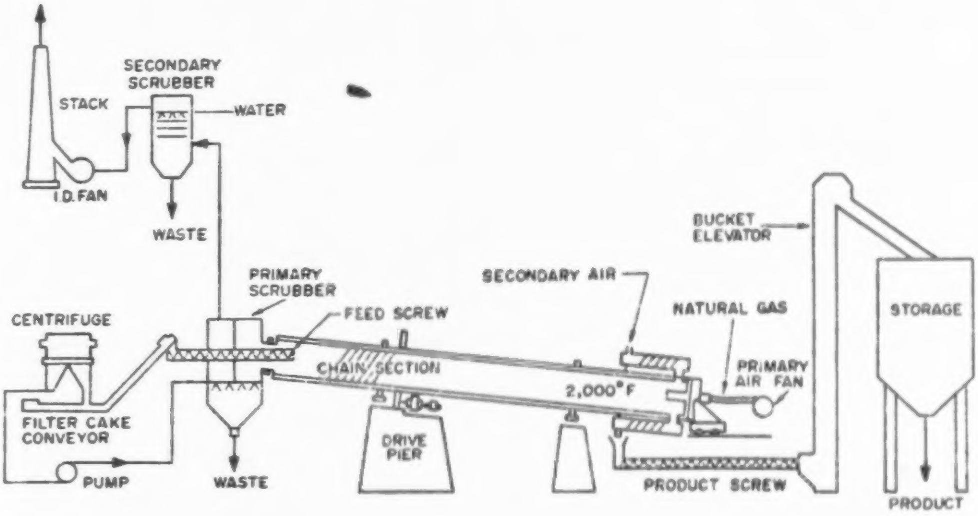
STACK
SECONDARY SCRUBBER
WATER
I.D. FAN
WASTE
PRIMARY SCRUBBER
FEED SCREW
CENTRIFUGE
CHAIN SECTION
FILTER CAKE CONVEYOR
PUMP
WASTE
DRIVE PIER
SECONDARY AIR
NATURAL GAS
2,000°F
PRIMARY AIR FAN
BUCKET ELEVATOR
STORAGE
PRODUCT SCREW
PRODUCT

Figure 10. Rotary kiln dryer.

Various bulking materials can be used and suitable low cost materials include, previously composted sludge, wood chips, bark chips, rice hulls, and cubed solid waste. Unscreened finished compost has also been used. Generally, one part sludge (20 percent solids) is mixed with 2-3 parts bulking agent although this mixture can be varied depending on moisture content of sludge, type of bulking agent, and local conditions. The sludge-bulking agent mixture is then formed into the windrow or static pile as applicable.

Following composting, the product is removed from the windrow or static pile and cured in storage piles for 30 days or longer. This curing provides for further stabilization and pathogen destruction. Prior to or following curing, the compost may be screened to remove a portion of the bulking agent for reuse or for applications requiring a finer product. The compost can also be used without screening. Removal of the bulking agent also reduces the dilution of the nutrient value of the compost.

I.2.b.(1) Windrow - The sludge-bulking agent mixture, (2-3 parts of bulking agent by volume to one part of sludge) is spread in windrows with a triangular cross section. The windrows are normally 10 to 16 feet wide and 3 to 5 feet high. An alternative method of mixing the bulking agent and sludge and forming the windrow consists of laying the bulking agent out as a base for the windrow. The sludge is dumped on top of the bulking agent and spread. A composting machine (similar to a large rototiller) then mixes the sludge and bulking agent and forms the mixture into a windrow. Several turnings about (4 to 6 times) are necessary to adequately blend the two materials.

The windrow is normally turned daily using the compostor; however, during rainy periods turning is suspended until the windrow surface layers dry out. Temperatures in the windrow interior under proper composting conditions range from 55 to 65°C. Turning moves the surface material to the center of the windrow for exposure to higher temperatures. The higher temperatures are needed for pasteurization and kill off most pathogenic agents. Turning also aids in drying and increases the porrosity for greater air movement and distribution.

The windrows are turned for a two week period or longer depending on the weather and efficiency of composting. The compost windrow is then flattened for further drying. The cmpost is moved to curing when the moisture content has decreased to approximately 30 to 45 percent. Proper windrow composting should produce a relatively stable product with moisture content of 30 to 45 percent which has been exposed to temperatures of at least 50°C for a portion of time during the composting process.

The composting process requires longer detention times in cold or wet weather, therefore, climate is a significant factor with the windrow process in open spaces. Covering the composting area would significantly reduce the effects of cold weather and nearly eliminate the problems of wet weather. In any case, the curing area should be covered if operations are to be carried out during precipitation.

I.2.b.(2) Static Pile - The static pile composting method as applied to raw sludge requires a forced ventilation system for control of the process. The pile then remains fixed, as opposed to the constant turning of the windrow, and the forced ventilation system maintains aerobic conditions.

A base is prepared for the pile consisting of a 1 foot thick layer of bulking agent or previously composted unscreened product. A 4-inch diameter performated pipe is installed in the base as an aeration header. The base is constructed with a typical plan dimension of approximately 40 by 20 feet. The sludge-bulking agent mixture is piled on this base to a height of approximately 8 feet to form a triangular cross section. The pile is capped with a 1 foot layer of screened compost product. This top layer extends down the sides to help absorb odors and to act as a shield or roof against penetration of precipitation. A typical static pile is illustrated in Figure 11. An alternative configuration is the extended static pile method where subsequent piles are "added" to the initial static pile. This configuration saves space compared to a number of separate static piles.

The perforated underdrain pipe is attached to a blower by pipe and fittings. The other side of the blower is piped to a smaller, adjacent pile of screened compost product. Air and gases are drawn by the blower from the static compost pile and discharged through the small pile of product compost. The small pile effectively absorbs odors. The operating cycle of the blower is adjusted to maintain oxygen levels in the exhausted gases and compost pile within a range of 5 to 15 percent. Temperatures within the compost pile will vary somewhat with monitoring location in the pile, but should reach 60-65°C. Normally the blower is operated on an on-off cycle to maintain proper oxygen levels and temperatures within the pile.

After an average composting period of 3 weeks, the compost is moved to a curing area.

Outdoor temperatures as low as -7°C and rain totaling 7 inches per week has not interferred with the successful outdoor operation of exposed static pile composting. Temperatures produced during static pile composting are generally above 55°C and often exceed 70 to 80°C.

I.2.b.(3) Mechanical Systems - There are several mechanical systems available for composting. Most are designed for solid waste composting where the much larger quantities of material to be composted make the reduction in land requirements due to mechanical compostors cost effective. The volume of sludge to be composted at most operations is very small when compared to solid waste system and mechanical compostors have not been found to be advantageous.

In general mechanical compostors consist of large vats or digesters with mechanical equipment for aeration, mixing, and moving the compost through the digester. Additional information on mechanical composting and European experience is given in reference (53). These systems are proprietary.

I.2.c. Co-disposal with Solid Waste

Co-disposal of sludge and solid waste by composting usually takes one of two forms:

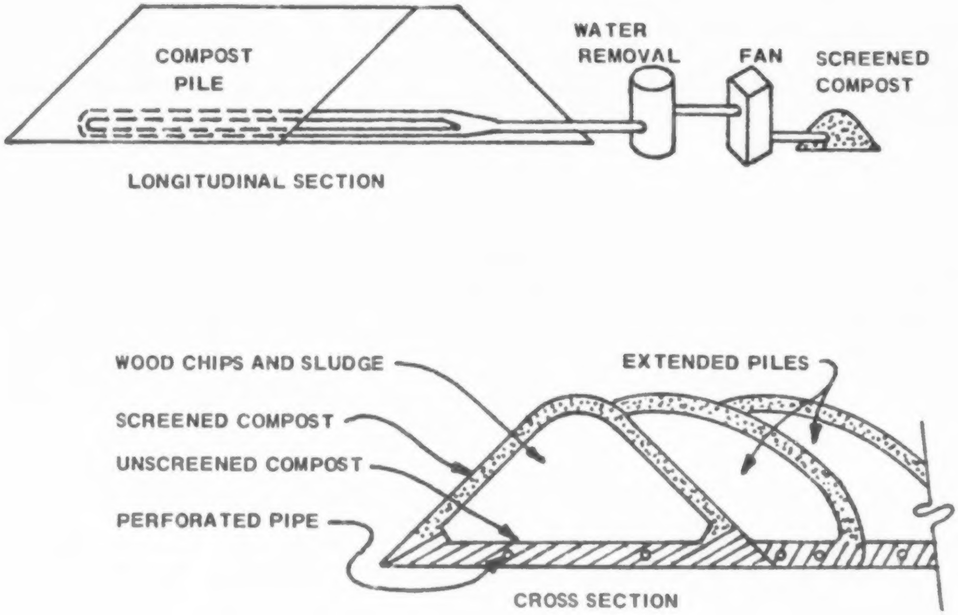
COMPOST PILE
WATER REMOVAL
FAN
SCREENED COMPOST
LONGITUDINAL SECTION
WOOD CHIPS AND SLUDGE
EXTENDED PILES
SCREENED COMPOST
UNSCREENED COMPOST
PERFORATED PIPE
CROSS SECTION

Figure 11. Static pile composting.

- Use of shredded and classified solid waste as a bulking agent in sludge composting
- Use of sludge as a nutrient source in solid composting

Sewage sludge has too high a moisture content for successful windrow or static pile construction without the aid of a bulking agent. The cellulose (paper and some garbage) fraction of solid waste may offer a suitable and economical bulking agent. Solid waste on the other hand generally requires supplemental nitrogen and moisture for successful composting. Sewage sludge has been suggested as an economical source of additional nitrogen (54).

I.2.d. Nutrient Enrichment

It may prove cost-effective to increase the market value of the sludge product by nutrient enrichment. While nitrogen and phosphorus contents can be increased with a subsequent increase in value, the greatest nutrient shortcoming of most sewage sludge products is the potassium (potash) content. Nutrient enrichment processes may be part of the sludge management system or they may be practiced by fertilizer processors who purchase unenriched product from the wastewater agency.

I.3. PACKAGING AND DELIVERY

The facility plan must give adequate consideration to the methods of product packaging and delivery, as they may determine the success or failure of the composting system.

By far the most common system of delivery sludge for off-site use by others is to allow or encourage individuals to pick up lagoon or bed dried sludge at the treatment plant. Usually the sludge is given away, or a nominal price charged, if it is loaded by the user. If the sludge is loaded by the utility a higher price is often charged to off-set labor costs.

The same concept is sometimes applied to larger deliveries, with user owned trucks loaded with sludge during regularly scheduled drying bed or lagoon cleanings.

Sludge product is often delivered in bulk to the users. Trucks, railroads, and barges have been used. The section on sludge transport has more information on the selection of transportation modes.

Bagging of the sludge product is a costly process, but the bagged product can usually be sold at a correspondingly higher price. Many urban and suburban individual users will desire small quantities of sludge product and will not have the means for transporting the unbagged product. This segment of the potential market is accustomed to obtaining fertilizers and soil conditioners in bagged form and is generally willing to pay a premium for the convenience. The bagged product can be sold at the treatment plant site, although the visibility afforded by marketing through the usual outlets such as garden centers and nurseries can greatly improve sales. Regulatory agencies should be consulted to determine required labeling.

Section J - COST EFFECTIVENESS ANALYSIS

In order to select the best sludge management alternative, a cost-effective analysis must be performed. The cost-effectiveness analysis may be on an amortized annual basis or on a present worth basis, but all alternatives must be evaluated in the same manner. Whether on an annual or present worth basis, the analysis should include the costs of construction, operation, maintenance and supervision for all components of the sludge management system, including sludge treatment processes and any impacts on the wastewater treatment processes.

Cost-effectiveness analyses should be made in accordance with the Federal regulations "Cost-Effectiveness Analysis Guidelines" (55).

In evaluating systems which involve co-disposal with solid waste, great care must be exercised to insure that the costs used reflect the actual situation. Some examples follow:

- When solid waste and sludge are to be managed in an all new facility, the total cost of managing both waste streams together should be used. In evaluating alternative sludge management systems not involving co-disposal, the cost of separate solid waste management should be included.

- Where sludge is to be added to an existing solid waste management system, the incremental cost of the sludge management should be evaluated.

- Where solid waste is added to a sludge management system as raw material (refuse-derived fuel or bulking agent), the cost of separating usable material from the overall solid waste stream and inserting it in the sludge management stream should be treated as a variable annual cost to the sludge management system for fuel or material. Credit for an incremental reduction in the solid waste stream may be taken, although the volumes involved may not justify this.

- Cost must be allocated between the sludge management system and the solid waste management system according to EPA policy to determine separate agency shares.

This section discusses only quantifiable costs. Such non-quantifiable costs as social and environmental costs are discussed under the section on environmental assessment; and the performance of a separate energy-effectiveness analysis is discussed in the section on energy analysis.

Comparative cost information which may be useful may be obtained from the technical report, A Guide to the Selection of Cost-Effective Wastewater Treatment Systems, (56) in conjunction with its supplement, An Analysis of Construction Cost Experience for Wastewater Treatment Plants, (57).

J.1. GENERAL CONSIDERATIONS

J.1.a. Planning Period

The planning period for cost-effectiveness analyses is 20 years.

J.1.b. Discount Rate

The discount, or interest rate to be used in cost-effectiveness analyses is the rate established by the Water Resources Council for water resources projects. Discount rates are normally revised on October 1 of each year.

J.1.c. Construction or Other Cost Indices

Cost vary with time and with geographical location. All usable cost data will be referenced to a specific place and point in time. Cost indices must then be applied to the data to adjust them to the conditions under consideration. Adjustment is performed by multiplying the cost data by the ration of the current cost index to the cost index for the place and time for which the data was compiled. The most useful indices (which are all published in Engineering News-Record) are:

- The Engineering News-Record Construction Cost Index
- The EPA Sewage Treatment Plant Index
- The EPA Sewer Construction Cost Index

J.1.d. Service Lives of Facility and Equipment

The cost-effectiveness guidelines give service lives for various components of the wastewater treatment system. These service lives are generally applicable to sludge management systems. Many components of sludge management systems, however, do not fit into the categories in the cost-effectiveness guidelines, and consideration should be given to establishing more accurate service lives. Where the sludge management system has a useful life less than the planning period, as is often the case with landfills, the cost of sludge management for the remainder of the planning period must be included in the analysis. In evaluating service lines consideration must also be given to the salvage values of facilities and equipment at the end of the project life.

J.1.e. Capital Costs and Credits

Capital costs and credits include such items as:

- Land or right-of-way purchase
- Facility construction including engineering, administration, construction cost, fixed equipment costs, start-up costs, and interest during construction.

- Mobile equipment costs including trucks, tractors, etc.
- The incremental cost of increasing wastewater treatment unit sizes to accommodate sidestreams.
- Credit for salvage values of land and equipment if applicable.

In evaluating the cost of land acquisition, consideration should be given to any losses in property tax revenues due to public ownership of the property.

J.1.f. Fixed Annual Costs

Fixed annual costs are those costs which are incurred regardless of the actual flow to the sludge management system. These costs include operating labor, maintenance, supplies, monitoring, equipment leasing, and land leasing. Inflation of material and wages should not be considered unless a change in the relative costs of portions of the fixed annual costs can be anticipated.

J.1.g. Variable Annual Costs and Credits

Variable annual costs and credits are those which change with the sludge flow. These costs and credits include:

- Fuel
- Electricity
- Chemicals including supplemental fertilizer
- Incremental operation and maintenance costs of sidestream treatment
- Credits for energy recovery
- Contract haul costs
- Cost of product disposal or credit for product sale
- Bulking agent costs
- Product packaging costs

J.2. SLUDGE TREATMENT

The cost of sludge treatment (thickening, stabilization, conditioning, dewatering) is a major portion of any sludge management system. Detailed analysis of sludge treatment costs must be made for each alternative under consideration. In addition, possible alternative sludge treatment systems for each management alternative should be analyzed for their effect on the overall cost. Sludge treatment costs should not neglect the incremental addition to wastewater treatment costs due to the return of sidestreams to the wastewater processes.

J.3. SLUDGE TRANSPORT

Each sludge transport system under consideration should be analyzed for its cost-effectiveness. It should be recognized that each sludge management alternative will have a different set of sludge transport costs to evaluate. Data on sludge transportation costs can be found in the EPA publication Transport of Sewage Sludge (16).

J.4. LAND APPLICATION

Cost-effectiveness analyses for land application systems should include credit for the sale of any crop produced on land owned or leased by the wastewater agency. The O&M costs for site preparation and sludge application can be partially offset by a credit for the increased real value of the land (real deflated value) resulting from the reclamation project. Land application systems should be given 115 percent cost preference over other disposal systems in accordance with EPA regulations on innovative/alternative systems. The credit for the value of the reclaimed land should be based on the estimated market value of the reclaimed land at the time the analysis is made. Conversely, if the intended crop is unsalable, the cost of crop disposal should be included; and if land application of sludge makes previously usable farm land permanently unsuitable for food chain crops, consideration should be given to a possible loss in market value. Area funding agencies should be contacted for their acceptance considering these concepts.

J.5. LANDFILL

If the life of the landfill is less than the planning period, as is often the case, the cost of sludge management through the remainder of the planning period should be considered.

J.6. COMBUSTION

Analyses of combustion processes should consider the value of any energy recovered in the form of waste heat or as pyrolysis products, the cost of residue disposal, and the cost of sidestream treatment. It is possible that the combustion process residue may have a market value, either as is, or after further processing.

J.7. SLUDGE FOR OFF-SITE USE BY OTHERS

Analysis of off-site use alternative should include a realistic assessment of the market value of the product. Considered in the evaluation of the product value should be the cost of transporting it to the user.

Section K - RELIABILITY

The reliability of the sludge management alternative under consideration must be evaluated. Sufficient reliability should be designed into the sludge management system to prevent undesirable effects resulting from system interruptions. The EPA technical bulletin Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability (58) should be consulted in evaluating the reliability of the proposed facility.

K.1. MECHANICAL DOWNTIME

The sludge management system chosen should include features which minimize the effects of mechanical downtime. Mechanical downtime usually occurs as a result of:

- Scheduled maintenance
- Power failures
- Equipment failures

K.1.a. Standby Power Supply

In general, the nature of sludge management systems is such that power failures of typical duration have no serious effects on the system operation. A notable exception, however, is the multiple hearth incinerator. Loss of power to the rabble arm drive and cooling air supply can result in serious damage to the rabble arms and center shaft. Standby power should always be provided for at least the rabble arm drive and cooling air fan. Whenever possible, standby power should also be provided for the induced draft fan, as it is quite costly, and sometimes damaging, to permit a multiple hearth furnace to cool and to subsequently reheat it.

K.1.b. Standby Fuel Supply

It is sometimes desirable to have a standby source of fuel. This is particularly true in the case of multiple hearth incinerators on interruptible natural gas supplies. It is very costly to permit an operating multiple hearth incinerator to cool down as a considerable amount of fuel is required to bring it back up to operating temperature. In addition, uncontrolled cooling can result in refractory damage.

K.1.c. Storage

Sludge storage is often the most economical way to provide adequate reliability. Storage has the added benefit of providing operating flexibility at the sludge disposal site, possibly allowing 8-hour, 5-day work schedules and shutdown during inclement weather. Storage should be sized to accommodate the entire sludge production from the wastewater treatment facility during the longest anticipated outage due to mechanical downtime. Where operating flexibility is also a goal of sludge storage, the sizing of the storage facility will often be governed by the flexibility requirement.

K.1.d. Duplicate Equipment

The provision of multiple process units can provide protection from mechanical downtime for scheduled maintenance or equipment failure. This approach is most often applicable to larger facilities which handle a quantity of sludge several times the capacity of a typical sludge processing unit. An example would be a sludge incinerator installation with four incinerators, three of which can, when operating at peak capacity, handle the full sludge production of the wastewater treatment facility. Care should be taken to insure that duplicate items of equipment are not subject to "common mode" failures, such as loss of a single gas line which serves all incinerators. Storage can often be considered as an alternative to duplicate equipment.

K.1.e. Backup Equipment

In the case of landfill and land application facilities, and some composting operations, protection against mechanical failure can be provided by backup equipment. Backup equipment can often be multi-purpose, such as a tractor with dozer blade which can serve as a backup at a landfill site for more specialized excavating, compacting, backfilling, and road grading equipment. Often it is not necessary for the backup equipment to be dedicated to the sludge landfill site. Backup equipment for a landfill might be obtainable by agreement from the local solid waste landfill operation, the local public works department, or from other utilities in the area. In many communities it may be possible to rent the necessary backup equipment as needed from a local heavy equipment rental agency.

K.1.f. Alternative Management Techniques

The planning of an alternative sludge management technique can protect a facility from mechanical downtime. An example would be an incineration facility with provisions for hauling sludge to a solid waste landfill in the event of incinerator failure. Care should be taken, however, that the alternative management system is not subject to "common mode" failures with the principal management system.

K.2. AVAILABILITY OF NEEDED RESOURCES

A key factor in determining the reliability of the sludge management system is the availability of the resources necessary to operate the system. An otherwise well planned and designed system will not function reliably if these resources are in short or unreliable supply.

K.2.a. Electric Power

The supply of power from the local electrical utility must be considered in the early stages of facility planning. Frequently the electric utility will be forced to construct new lines, the cost of which may be charged to the sludge management operation. These costs should be included in the cost-effectiveness analysis in a manner appropriate to the billing schedule.

K.2.b. Fuel

The supply of necessary fuels must be assured. If gas is required, the ability of the local gas utility to provide service should be verified as service is often on an interruptible basis. This will further affect fuel supply reliability.

If liquid fuels are required, the local fuel marketing system's capability for meeting the requirements of the sludge management system must be addressed. Marketing capabilities must be matched to the system design (frequency of delivery, size of delivery, etc.). Adequate on-site fuel storage should be considered to allow for delivery delays.

K.2.c. Chemicals

The local availability of necessary chemicals must be considered. The ability of the local chemical marketing system to reliably meet the facility's needs must be assessed. The system design must be matchable to the marketing capabilities (frequency of delivery, size of delivery, etc.). Sufficient on-site storage should be considered to allow for delays in deliveries.

K.2.d. Manpower

The ability of the local labor market to supply the needed qualified personnel at the salary levels established for the sludge management operation must be examined. Qualified maintenance personnel should be available in the local labor market. In the case of agricultural operations, people with farming experience must be available. If qualified heavy equipment operators are required, their availability must be considered.

K.2.e. Replacement Parts

The availability of replacement parts for the sludge management system equipment is critical to system reliability. In many small communities, spare parts for even relatively common types of equipment may require long delivery times. Machine shops may be locally available which could, in an emergency, fabricate difficult-to-obtain parts.

K.3. FACTORS OF SAFETY

The design of the sludge management system should include factors of safety to allow for abnormal sludge quantities and characteristics, unusual periods of inclement weather, droughts, and other reasonably foreseeable occurrences.

Section L - ENERGY ANALYSIS

The energy-effectiveness of sludge management alternatives must be analyzed in order to determine the effect of the facility on energy production and consumption in the planning area. The EPA's "Grants Regulations and Procedures, Revision of 40CFR30, 420-6" (59) requires all portions of the wastewater treatment system, including sludge management systems, to be energy-efficient. The economics of energy utilization are considered in the cost-effectiveness analysis.

Energy analyses must consider both the primary energy consumption (used in the operation of the management system) and secondary energy consumption (used in the manufacture of consumables used by the management system). Energy analyses should present all alternatives on a common basis. In the case of co-disposal alternatives, the energy consumption of both solid waste and sludge management should be considered for both the co-disposal alternative itself and alternatives not involving co-disposal. Credits for energy recovery should be based on realistic estimates of the actual utilization of that energy. Credit for recovery of steam from waste heat, for instance, should only be considered if a viable use for the steam exists. Energy analyses should also include the energy consumed in treating sidestreams.

Energy-effectiveness must be evaluated within the framework of cost-effectiveness. Theoretically, the two should be similar, but for a variety of reasons this may not be the case. For instance, the regional fuel price structure is variable and will reflect the relative availability of a particular type of energy, such as fuel oil, natural gas, coal, or nuclear. Thus, a particular sludge management system might be energy- as well as cost-effective in one region, while only energy-effective in another. Similarly, while the energy-effectiveness of a particular system might be high, the cost-effectiveness might not reflect this fact if the system is labor intensive and labor costs are high for a particular project.

The EPA publication Energy Conservation in Municipal Wastewater Treatment (40) contains more detailed guidance on making energy-effectiveness analyses as well as a great deal of primary and secondary energy consumption data.

Section M - ENVIRONMENTAL ASSESSMENT

An assessment of the impact of the sludge management system on the environment, including public health, social, and economic impacts, is required for all federally funded projects. Similar assessments are required by many state and local governments. The impact of each sludge management alternative under consideration must be evaluated.

M.1 ENVIRONMENTAL IMPACT

Sludge management systems may affect the following components of the environment: (1) soil and vegetation, (2) groundwater, (3) surface water, (4) animal and insect life, (5) air quality and (6) climate.

M.1.a. Soil and Vegetation

The effects of the deposition of sludge on the land may be adverse or beneficial, or some combination of the two, depending on the character of the material deposited, the manner in which it is deposited, and the character of the land. (See Section F and I).

M.1.b. Groundwater

Groundwater quality, level, and flow will normally be affected, to a minor extent, by sludge management techniques which place sludge on or in the land.

Effects on groundwater quality is the most significant. Leachate moving from a sludge land application or landfill site to groundwater by percolation can contain significant concentrations of substances which are considered to be pollutants. The sludge constituent typically of most concern is nitrate-nitrogen. Other constituents which may leach from sludge into the groundwater include phosphates, heavy metals, organics, dissolved solids, and others identified under article B.2.

M.1.c. Surface Water

Surface water flow and quality can be affected by an improperly designed or operated sludge management system. Flow can be increased or decreased by the alteration of runoff patterns due to grading at a landfill or land application site. Surface water quality can be adversely affected by allowing runoff from the site to enter surface waters. Any of the constituents of the sludge could enter surface water with the runoff.

When sludge is transported by barge, the additional possibility of surface water pollution due to sludge spills must be evaluated.

M.1.d. Animal and Insect Life

The impact of sludge management systems on animal and insect life is normally minimal. Where sludge is being deposited in or on previously unfarmed land, the natural habitat of certain species may be disrupted. Conversely, the production of crops on land with applied sludge may provide additional food sources for wildlife. These and other effects must be evaluated for each species of concern.

M.1.e. Air Quality

Sludge incineration and heat drying processes may have a significant impact on air quality. Among the air pollution components which may be produced by these processes are:

- Particulates
- Sulfur dioxide
- Oxides of nitrogen
- Heavy metals
- Toxic organic compounds
- Hydrocarbons and carboxyls

The evaluation of the impact on air quality should consider each of these pollutants as well as any other substances which may be formed in the atmosphere from these pollutants, such as photochemicals.

Sludge transport by truck, barge, or rail will have an impact on air quality due to vehicle emissions. The nature and quantity of the pollutants from internal combustion engines is well documented (60) and will not be discussed further here. Land application systems which utilize spraying of sludge may lead to the production of aerosols (finely divided airborne moisture). The chief concern with aerosol production is the possibility of pathogens entering human or animal respiratory systems.

All sludge management systems have the potential for odor production to some degree or another. While odors are indicative of the presence of polluting substances, primarily hydrocarbons and hydrogen sulfide, their primary adverse effect is aesthetic. Odors will be discussed further under article M.3. Social Impacts.

M.1.f. Climate

The effects of sludge management systems on climate are minimal, generally limited to a small increase in humidity in the immediate vicinity of the project. This increase may be due to evapotranspiration at land application sites or heat evaporation at incineration or heat drying projects.

M.2 PUBLIC HEALTH IMPACTS

Public health impacts must receive careful attention in the facility plan. Most public health effects of sludge management systems are the result of impacts on animal and insect life, soils and vegetation, groundwater quality, surface water quality, or air quality.

M.2.a. Disease Vectors

Several of the animals and insects which are known to thrive in certain sludge management systems are also known to be vectors for several diseases of man and animals. Of particular concern in this regard are rodents, notably rats and mice, flies and mosquitoes.

Rodents are particularly troublesome on sites which employ the co-disposal of sludge with solid waste by landfill or composting. The solid waste provides food and harborage for the rodents, while the sludge may provide a source of pathogenic organisms. The existence of large numbers of the rodents in a small area such as a landfill can enhance the spread of the diseases from animal to animal and thence to the human population. Proper operation of a landfill or composting operation can minimize the rodent problem.

Flies are a potential problem with virtually all sludge management systems. They find sludge storage and disposal sites to be very hospitable, feeding directly on most sludges and laying their eggs within the sludge. Aside from the aesthetic problems associated with flies, they are mechanical disease vectors, carrying small particles of potentially pathogenic sludge on their bodies and legs. Upon contacting human beings or human food, the pathogenic organisms may be transmitted to people. Fly control is primarily a matter of keeping the sludge covered to prevent the emergence of larvae. Well-compacted, daily cover at landfill sites will help control flies. Mosquitoes are known to transmit several pathogenic organisms.

Mosquitoes breed in standing water. The most effective method of mosquito control is proper grading of the site to prevent ponding of water.

M.2.b. Soil and Vegetation

Soil and vegetation impacts are of concern to public health when crops grown on land application or landfill sites or with the aid of sludge by-products may be introduced into the human food chain. In this event, toxic substances deposited in the soil with the sludge may be transferred to the crops, and thence to human beings.

M.2.c. Groundwater Quality

The effects of sludge management or groundwater quality are a public health concern whenever an aquifer is, or may be, used as a potable water supply. Leachate capture and treatment may be required in order to protect the aquifer. Nitrate pollution is the most common problem, but toxic organics, dissolved salts, trace elements, and pathogens must be considered. Adequate leachate monitoring and control practices must be included in the facility plan.

M.2.d. Surface Water Quality

Surface water quality is a public health concern when runoff from a sludge management site enters a receiving water which is used as a potable water supply for recreational activities involving bodily contact with the water, or for commercial or recreational fishing. A properly planned landfill or land application site will include grading to divert runoff around the site and/or to capture and treat the runoff before it enters the receiving water.

M.2.e. Air Quality

Air quality is a public health concern from two standpoints: an increase in the incidence of respiratory diseases from the increase in the general air pollution level due to sludge combustion, heat drying or transport activities; and the possibility of aerosol-borne pathogens from spray-type land application sites.

Well-operated sludge incineration facilities with modern pollution control equipment have a relatively low potential for air pollution when compared with, for example, automobiles (61). The facility plan must define the operating parameters for minimizing air pollution. The facility plan must take into account the current federal, state, and local air quality regulations and policies. Other public health effects of sludge combustion process pollutants and the resultant products (photochemicals) must be evaluated in the facility plan.

Aerosols are most successfully controlled by limiting their travel. This can be done by use of buffer zones, vegetation, proper sprayer design, and scheduling of spraying.

M.3. SOCIAL IMPACTS

The impact of sludge management on the sociological aspects of the community must be evaluated.

M.3.a Relocation of Residents

Sludge management by land application or landfill often requires substantial quantities of land. This may lead to relocation of residents. For projects involving federal funds, land acquisition procedures must comply with the Uniform Relocation Assistance and Land Acquisition Policies Act of 1970 (62). Inconvenience to residents must be weighed against the advantages of the sludge management system.

M.3.b. Greenbelts and Open Spaces

Proposed sludge management systems should be evaluated with regard to their effect on greenbelts and open spaces. While sludge management systems may disrupt existing open space, existing damaged land, such as abandoned strip mines, may be reclaimed for use as open space by land application and landfill operations.

M.3.c. Recreational Activities

Sludge management systems may affect recreational activities by disruption of existing parks or open space, by eventual creation of new parks or open space, by improvement of existing parks where sludge is used off-site by the local parks department, or by the deleterious effects of site run-off on recreational waters.

M.3.d. Community Growth

Unless the sludge management system is the capacity-limiting element of the overall wastewater treatment system, the sludge management technique selected will have only a minor effect on the rate of community growth. The overall wastewater treatment system, of which the sludge management system is only one part, may however, have a major effect on the rate of community growth.

The patterns of community growth may be greatly affected by the sludge management system. Certain sludge management systems may deter residential growth in the vicinity of the facility, while encouraging industrial growth. The availability of recovered energy, for instance, will rarely be so significant as to affect the decision of a new industry to move to a community, but it could conceivably be a factor in determining the exact site for the industrial development. The effects of sludge management on the patterns of growth will affect the growth patterns of other community services, which must be evaluated in the impact assessment.

M.3.e. Noise and Odor

Noise and odor are primarily aesthetic concerns which affect the other sociological aspects of the sludge management system. Nearly all sludge management systems must consider odor problems. Noise problems are normally associated with sludge transport by truck and with landfill, land application and composting operations. The facility plan should address these problems and formulate methods of dealing with them. Appropriate scheduling of operations can be of great value in minimizing noise problems. Adequate stabilization and prompt disposal of sludge can be of value in reducing odor problems by eliminating septic conditions in uncovered sludge.

M.4. ECONOMIC IMPACT

The facility plan should consider the effects of the sludge management system on the economy. The effect of the system on the value of the site itself and of adjacent property must be evaluated. The sludge management system may affect the overall economy in terms of jobs created and land removed from agricultural production. Public ownership of the sludge management system property may affect the community tax base. The overall effect of the sludge management system on the supply of resources and energy must be considered.

Section N - IMPLEMENTATION PROGRAM

Selection of the sludge management system is based on technical feasibility, cost-effectiveness, flexibility, reliability, energy-effectiveness, and overall impacts. At all stages of the planning processes the public must be involved in order to aid the planner in selecting the most cost-effective system, especially in considering non-monetary costs, and in assessing the impacts of the system.

N.1. PUBLIC PARTICIPATION PROGRAM

An appropriate, actively pursued public participation program can often make the difference between a sludge management system which has the support of the majority of the community and one which is unable to generate the support necessary for successful completion. Public resistance to sludge management systems is an almost universal phenomenon. This resistance is often rooted in misconceptions and lack of understanding of the problems and the alternative solutions, and in a feeling by the community that they have been excluded from the decision-making process. The resistance may also be due to valid concerns of the community of which the planner is not fully aware. A vigorous public participation program can educate the community concerning the problems and solutions of sludge managment, involve the public in a constructive manner in the planning process, and serve as a valuable information-gathering tool for the planner, assisting him in assessing the impacts of the system on the community. The public participation plan must be tailored to the scope of the project and to the potential for community concern.

Public involvement in the planning process can, of course, slow the process and may result in additional cost. On the other hand, a lawsuit brought by uninformed members of the community to halt a sludge management program in the final stages of planning, or even during costruction, can be far more costly, and can delay the project for a much longer period of time. While a public participation program will not eliminate resistance to a proposed sludge management system, it may be able to reduce that resistance to a manageable level. The EPA publication Process Design Manual for Municipal Sludge Landfills (34) has a great deal of information on the design of public participation programs which, while written primarily for landfill systems, is generally applicable to all sludge management systems.

N.2. POTENTIAL ROADBLOCKS

The facility plan should identify potential roadblocks to implmentation of the plan. Typical items which may be considered are:

- Public resistance to the plan
- Inability to obtain necessary financing
- Difficulty in acquiring land
- Where the plan involves a contract with a private concern, such as use of sludge as a raw material by a fertilizer manufacturer, failure to execute the anticipated contract.

N.3. LAND ACQUISITION PROGRAM

The facility plan should include a proposal for land acquisition. If the required land is not already owned by the authority operating the sludge management system, it may be acquired by:

- Negotiated purchase of land or right-of-way
- Leasing of land
- Purchase by condemnation of land or right-of-way
- Dedication of land already owned by the sludge-managing authority or another related authority to the sludge management system

N.4. IMPLEMENTATION SCHEDULE

The facility plan should include a schedule for project implementation. The schedule should include anticipated start and stop dates for each major activity. The schedule should take into account possible delays in implementation.

The schedule should be broken down to the level of detail justified by the scope of the project. As a minimum, the following major tasks should be included:

1. Facility plan approval
2. Land acquisition
3. Design
4. Design approval
5. Construction
6. Operation

Graphical presentation of the schedule is often useful as an aid to understanding.

N.5. STAFFING PLAN

A preliminary project staffing plan should be included to permit the operating authority to begin the process of hiring and training personnel at the most appropriate time. The staffing plan should consider needs in the following general categories:

- Operations
- Maintenance
- Supervisory
- Laboratory
- Administrative

The staffing plan should be developed to a level of detail justified by the project scope.

N.6. COMPATIBILITY WITH REGULATIONS

The facility plan must include an evaluation of the proposed sludge management system compatibility with the applicable federal, state and local laws and regulations.

N.6.a. Zoning and Land Use

The plan must take into consideration local and regional zoning ordinances and land use plans. The proposed sludge management system must be compatible with the planned growth patterns of the community.

N.6.b. Solid Waste Disposal

The management of sludge is governed by the Resource Conservation and Recovery Act (2), the Toxic Substances Control Act (63) and federal regulations pertaining to the disposal of solid waste as well as those pertaining to wastewater treatment. In addition, many states regulate sludge disposal under their solid waste regulations whenever the material is removed from the treatment plant site, as for land application or landfill.

N.6.c. Air Pollution Control

Sludge incinerators must comply with the "New Source Performance Standards for Sludge Incinerators" (43, 47, 64), the applicable provisions of the Toxic Substances Control Act (63) and any applicable federal regulations. In addition, sludge incinerators and dryers must comply with the mercury limitations of the "Amendments to the National Emission Standards". Many state, regional, and local governments have air pollution control requirements which are more stringent than the federal requirements, all of which must be met.

N.6.d. Water Pollution Control

The sludge management system must comply with the Clean Water Act (65), Federal Water Polution Control Act (4), the Resource Conservation and Recovery Act (2), and the Toxic Substances Control Act (53), and all applicable federal regulations. Any applicable state or regional laws and regulations must also be met. Until groundwater protection criteria are developed under the Resource Conservation and Recovery Act, the groundwater protection criteria in the EPA publication Alternative Waste Management Techniques for Best Practicable Waste Treatment (66) shall be used.

N.6.e. Public Health

Applicable state and local regulations regarding pathogen destruction must be complied with. These regulations often deal specifically with hospital wastes, and sludge to which public access is permitted or encouraged.

PART II

DESIGN AND SPECIFICATIONS

DESIGN AND SPECIFICATIONS

INTRODUCTION

The design and specifications package should be a logical extension of the facility plan. The design and specifications are for the purpose of implementation and construction of the sludge management system detailed in the facility plan. As an aid to the evaluator, basic design criteria should be included with the package.

The format of this checklist has been selected to enable the reviewer to enter a checkmark or comment to the right of each item. There are 6 major categories:

A. Agreement with Facilities Plan
B. Sludge Transport
C. Land Application
D. Landfill
E. Combustion
F. Off-Site Use of Sludge by Others

Within each category are numerous sub-elements. All the major categories should usually be included. It is not necessary that all the sub-elements be included. References are given for more detailed information and design criteria. In particular, the EPA Process Design Manual for Sludge Treatment and Disposal (1) should be consulted for specific design information. It is not the intent of the supporting commentary to limit alternatives to just those discussed. A particular technique or process may be described as "best" or as "typical" but this does not mean that other procedures are unacceptable.

DESIGN AND SPECIFICATIONS

CHECKLIST

A. AGREEMENT WITH FACILITIES PLAN
  1. MODIFICATIONS
  2. CHANGES IN REGULATIONS AND POLICIES CONSIDERED
     (In Federal, State, and Local regulations; in local or regional land use plans.)

B. SLUDGE TRANSPORT
  1. SLUDGE CHARACTERISTICS
     a. Quantity: Maximum, Average, Minimum
     b. Solids Content
     c. Odor Potential
  2. PIPELINE
     a. Alternate Routes Considered
     b. Distance
     c. Elevation Changes
        (Air relief, vacuum relief)
     d. Operating Program
     e. Pipe Selection
        (Velocity, maximum and minimum, size, material, friction losses, corrosion control)
     f. Pumping Facilities
        (Number and location of pumping stations, number and type of pumps, pumping energy, station structure, station utilities, controls.)
     g. Pipeline Cleaning Provisions
     h. Emergency Operation
        (Storage, standby power.)
     i. Excavation Conditions Verified
        (Soil conditions, other underground utilities, highways, rail crossings.)
     j. Methods of Right-Of-Way Acquisition
        (Existing utility easements, negotiation with landowners, condemnation.)
  3. TRUCKS
     a. Alternate Routes Considered
     b. Haul Distance, Speed and Travel Time
     c. Compatability of Proposed Route with Existing Road and Traffic
        (Weight and height limits, turns required, speed limits, traffic congestion, road width, elevation changes, traffic control (stops, etc.).)
     d. Operating Schedule
        (Loading time, haul time, unloading time, return time fueling and daily maintenance.)
     e. Fuel Consumption
     f. Manpower Requirements

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   g. Truck Selection and Acquisition ________
      (Size, type, quantity, useful life, purchase lease.)
   h. Contract Haul Considered ________
   i. Facilities Required ________
      (Loading, unloading, vehicle maintenance, fueling, parking, washdown, sludge storage)

4. BARGE
   a. Haul Distance ________
   b. Barge Speed and Travel Time ________
      (Traffic, drawbridges, locks, tides, currents, and height limitations.)
   c. Operating Schedule ________
      (Loading time, haul time, unloading time, return time.)
   d. Barge Selection, Acquisition, and/or Tow Boat Acquisition ________
      (Towed or self-propelled, type, size, quantity, useful life, purchase, lease)
   e. Contract Haul Considered ________
      (Towing or complete operation.)
   f. Manpower Requirements ________
   g. Fuel Consumption ________
   h. Facilities Required ________
      (Loading, unloading, barge and tow-boat maintaenance, fueling, docking, and wash-down, sludge storage

5. RAILROAD
   a. Distance ________
   b. Speed, Load-Limiting Factors, and Travel Time ________
      (Clearance limitations, track conditions, traffic schedule)
   c. Operating Schedule ________
      (Loading, haul, unloading and return times)
   d. Car Selection and Acquisition ________
      (Type, size, quantity, useful life, purchase, lease, or railroad owned)
   e. Fuel Consumption ________
   f. Manpower Requirements ________
   g. Facilities Required ________
      (Loading, unloading, tank car maintenance, storage, and cleaning, sludge storage, siding extensions.)

6. ENVIRONMENTAL IMPACT ________
   (Air, land, surface water, groundwater, social, health, economic, historical, archaelogical impacts, and environmentally sensitive areas.)

7. REGULATIONS AND STANDARDS
   a. Surface Water Protection ________
   b. Sludge Loading and Unloading ________
   c. Construction Within Navigable Waterways ________
   d. Building Codes ________
   e. Reporting Spills ________
   f. Permits ________

C. LAND APPLICATION
- 1. SLUDGE CHARACTERISTICS
  - a. Type of Processing at Treatment Plant
  - b. Quantity: Maximum, Average, Minimum
  - c. Analysis
    (Concentration, particle characteristics, volatile, content nitrogen, phosphorus, potassium, heavy metals, pathogen content, pH
- 2. TYPE
  - a. Crop Utilization
    (Crop(s) chosen, tillage requirements, application/ crop growth timing, application method.)
  - b. Dedicated Disposal
    (Application method, tillage requirement.)
  - c. Land Reclamation
    (Present condition of site, soil-sludge reactions, application methods, tillage, requirements)
- 3. SITE CHARACTERISTICS
  - a. Topography
    (Limitations on application methods, erosion potential, crop compatibility.)
  - b. Runoff Control
    (From adjacent areas, on-site, storm flow added to liquid sludge quantity, cut-off trenches, embankments for runoff diversion.)
  - c. Soil
    (Soil Conservation Service soil maps; soil profiles: Location, physical properties, pH, CEC, heavy metals.)
  - d. Geohydrology
    (Map of geologic formations and discontinuities; groundwater: location. extent, use.)
- 4. DESIGN CRITERIA
  - a. Climatic Factors
    (Rainfall: quantity, duration, seasonal variation; wind velocity and direction, temperature variation)
  - b. Loading Rates
    - (1) Metals
      (Background level in soil, cation exchange capacity limits, projected from industrial changes or pre-treatment programs.)
    - (2) Nitrogen
      (Forms of nitrogen present, mineralization rate.)
  - c. Crops
    - (1) Nutrient uptake
      (Nitrogen, phosphorus, potassium, micronutrients.)
    - (2) Compatibility With Applications
      (Tillage requirements, timing of planting and harvesting, can application be made on growing crop, forage, have leaves been washed by rain or irrigation.)
    - (3) Harvesting requirement
      (Single harvest each year, multiple harvest each year, continual or intermittent harvest (grazing).)

5. SYSTEM COMPONENTS
    a. Dewatering ________
        (Percent solids achieved, chemicals used)
    b. Field Equipment ________
        (Compatibility with crops, compatibility with sludge, moisture content, compatibility with climatic factors.)
    c. Storage ________
        (Open, or covered; capacity to match non-operating periods, nuisance condition prevention methods.)
    d. Buffer Zones ________
        (Size, vegetation provided, fencing.)
6. MONITORING
    a. Land ________
        (pH, pathogens, available nutrients, heavy metals.)
    b. Crops ________
        (Yield, tissue analysis, disease control.)
    c. Water Quality ________
        (BOD, suspended solids, nutrients, coliforms, etc.)
7. RELIABILITY AND FLEXIBILITY ________
    (Expandability, storage, alternate sludge management techniques.)

D. LANDFILL
1. SLUDGE CHARACTERISTICS
    a. Type of Processing at Treatment Plant ________
    b. Quantity: Maximum, Average, Minimum ________
    c. Analysis ________
        (Concentration, particle characteristics, volatile content, nitrogen, inorganic ions, pathogen content, toxic organic compounds, pH.)
2. REGULATIONS AND STANDARDS ________
    (Sludge stabilization, sludge loading rates, frequency and depth of cover, distances to road, residences and surface water, monitoring, roads, building codes, permits.)
3. SITE CHARACTERISTICS
    a. Site Plan ________
    b. Soils ________
        (Depth, texture, structure, bulk density, porosity, permeability, moisture, ease of excavation, stability, pH, cation exchange capacity.)
    c. Geohydrology ________
        (Groundwater: Location, extent, use, geologic formations, discontinuities, surface outcrops.)
    d. Climate ________
        (Precipitation, evaportranspiration, temperatures, number of freezing days, wind direction.)
    e. Land Use ________
        (Present, final, adjacent property.)
4. LANDFILL TYPE
    a. Sludge Only Trench Fill
        (1) Narrow trench ________
        (2) Wide trench ________

b. Sludge Only Area Fill
  (1) Mound
  (2) Layer
  (3) Diked contaminent
c. Co-Disposal With Refuse
  (1) Sludge-refuse mixture
  (2) Sludge-soil mixture

5. LANDFILL DESIGNS
  a. Trench or Area Dimensions
    (1) Length
    (2) Width
    (3) Depth
  b. Berm Dimensions
  c. Trench or Area Spacing
  d. Sludge Depth
  e. Intermediate Cover Depth
  f. Final Cover Depth
  g. Bulking Agent
  h. Bulking Ratio
  i. Soil Importation

6. FACILITIES
  a. Leachate Controls
    (Adequate surface drainage, natural attenuation, soil liners, membrane liners, collection and treatment.)
  b. Gas Control
    (Permeable methods, impermeable methods, gas extraction.)
  c. Roads
  d. Soil Stockpiles
  e. Inclement Weather Areas
  f. Minor Facilities
    (Structures, utilities, fencing, lighting, washbacks, monitoring wells, landscaping, equipment fueling, storage and maintenance)

7. LANDFILL EQUIPMENT
  (Excavation, sludge handling, backfilling, grading, road construction.)

8. MANPOWER REQUIREMENTS

9. FLEXIBILITY AND RELIABILITY
  (Expansion potential, modification for change in sludge volume or type, equipment failure locally, storage.)

10. ENVIRONMENTAL IMPACTS
  (Air, land, surface water, groundwater, social, health, economic, historical, archeological impacts, and environmentally sensitive areas.)

E. COMBUSTION
  1. SLUDGE CHARACTERISTICS
    a. Type of Processing at Treatment Plant
    b. Quantity: Maximum, Average, Minimum
    c. Analysis
      (Moisture, heat value, nitrogen, sulfur, heavy metals, toxic organic compound.)

2. REGULATIONS AND STANDARDS
    a. Air Quality Requirements ________
       (Particulates, opacity, oxides of nitrogen, sulfur dioxide, carbon monoxide, heavy metals, toxic organic compounds, hydrocarbons and carbonyls, odors.)
    b. Permits ________
3. MULTIPLE HEARTH INCINERATION OR PYROLYSIS
    a. Operating Schedule ________
    b. Reactor Design
        (1) Hearth loading rate ________
        (2) Hearth area ________
        (3) Number of hearths ________
        (4) Reactor dimensions ________
        (5) Rabble speed ________
        (6) Rabble drive cooling air requirements ________
        (7) Sludge feed system ________
    c. Auxiliary Fuel System
        (1) Start-up ________
        (2) Continuous operation ________
        (3) Standby ________
    d. Combustion and Excess Air Requirements
        (1) Incineration ________
        (2) Pyrolysis ________
    e. Incineration Ash Systems
        (1) Handling
            (a) Truck ________
            (b) Slurry pipeline ________
        (2) Disposal
            (a) Landfill ________
            (b) Lagoon ________
            (c) Land application ________
            (d) Off-site use by others ________
    f. Pyrolysis Residue Systems
        (1) Gas ________
        (2) Tar ________
        (3) Char ________
    g. Air Quality Control
        (1) Afterburners ________
        (2) Scrubbers ________
        (3) Electrostatic Precipitators ________
4. FLUIDIZED BED INCINERATION
    a. Operating Schedule ________
    b. Reactor Design
        (1) Bed loading rate ________
        (2) Bed area and diameter ________
        (3) Reactor volume and height ________
        (4) Sand bed volume ________
        (5) Fluidizing air requirement ________
        (6) Sludge feed system ________
    c. Auxiliary Fuel Systems
        (1) Start-up ________
        (2) Continuous operation ________

      (3) Standby
   d. Combustion and Excess Air Requirements
   e. Incineration Ash Systems
      (1) Handling
      (2) Disposal
         (Landfill, lagoon, land application, reuse off-site by others)
   f. Air Quality Control
      (1) Afterburners
      (2) Scrubbers
      (3) Electrostatic precipitators

5. WET AIR OXIDATION
6. OTHER PROCESSES
   a. Cyclonic Reactors
   b. Electric Incinerators
   c. Proprietary Process
7. CO-DISPOSAL
   a. Refuse Disposal
   b. Refuse Derived Fuel
8. AUXILIARY FUEL SELECTION
   (Gas, oil, powdered coal, refuse derived fuel, electricity.)
9. RELIABILITY AND FLEXIBILITY
   (Expandable facilities, multiple units, alternative reduction and/or disposal methods, storage, standby power, standby fuel.)
10. MASS BALANCE
    a. Inputs
       (Dry solids in sludge, moisture in sludge, air, auxiliary fuel, make-up sand, and steam.)
    b. Outputs
       (Ash, combustible gas, tar, char, water, carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen, sand, excess air.)
11. ENERGY BALANCE
    a. Inputs
       (Solids heat of combustion, and auxiliary fuel heat of combustion, including after-burner.)
    b. Outputs
       (Latent heat of free moisture and moisture of combustion, sensible heat of gases of combustion, excess air, and moisture, sensible heat of ash, radiation, sensible heat of shaft cooling air, recovered energy for other plant other plant processes.)
12. ENERGY RECOVERY SYSTEMS
    a. Shaft Cooling Air Recycle
    b. Stack Gas Heat Exchange
    c. Reactor Water Jacket
    d. Wet Air Oxidation Effluent Heat Exchange
    e. Pyrolysis Product Recovery
13. ENVIRONMENTAL IMPACTS
    (Air, land, surface water, groundwater, social, health, economic impacts.)

F. SLUDGE FOR OFF-SITE USE BY OTHERS

- 1. SLUDGE CHARACTERISTICS
  - a. Type of Processing At Treatment Plant
  - b. Quantity: Maximum, Average, Minimum
  - c. Analysis
    (Moisture, nitrogen, phosphorous, potassium, heavy metals, toxic organic compound content, pathogens, heat content.
- 2. COMPOSTING
  - a. Bulking Agents
    - (1) Finished compost
    - (2) Refuse
    - (3) Wood products wastes
    - (4) Other wastes
  - b. Sludge Receiving and Mixing
  - c. Windrow composting
    - (1) Windrow construction
    - (2) Windrow mixing and turning
  - d. Static Pile Composting
    - (1) Pile construction
    - (2) Aeration system
    - (3) Recycle of air for pile heating
  - e. Mechanical Composting Systems
  - f. Curing
  - g. Screening
  - h. Facilities
    (Bulking agent storage area, curing area, screening, packaging, equipment storage, maintenance, and fueling areas, structures, utilities, fencing.)
  - i. Equipment
    - (1) Front end loader
    - (2) Windrow turner
    - (3) Aeration blowers and piping
    - (4) Mechanical composter
    - (5) Screens
    - (6) Dump trucks
- 3. DRYING
  - a. Drying Beds
    - (1) Surface area
    - (2) Sludge loading depth
    - (3) Base design
    - (4) Underdrain design
    - (5) Wall design
    - (6) Sludge removal
  - b. Drying Lagoons
    - (1) Surface area
    - (2) Lagoon depth
    - (3) Surface water control
    - (4) Berm design
    - (5) Decanting system
    - (6) Sludge removal

c. Heat Drying
  (1) Flash dryers
    (Flash drying cycle, incineration cycle, effluent gas cycle, product handling cycle.)
  (2) Rotary kiln dryers
    (Rotary kiln, sludge feed system, effluent gas system, product handling system.)
  (3) Air pollution control
    (Scrubber, filters, electrostatic precipitators.)
  (4) Auxiliary fuel
    (Gas, oil, coal, dried sludge, electricity.)

4. COMPOSTING WITH REFUSE
   (Refuse as a bulking agent or sludge as a nutrient source.)
5. NUTRIENT ENRICHMENT
6. PACKAGING
   a. Pick Up By User
      (User loads, utility loads.)
   b. Bulk Delivery To User
      (Truck, rail, barge.)
   c. Bagged
      (Sold at site, or sold through usual fertilizer outlets.)
   d. Instructions and Guidelines For Use
   e. Brand Name
7. ENVIRONMENTAL IMPACTS
   (Air, land, surface water, groundwater, social, health, and economic impacts.)

DESIGN AND SPECIFICATIONS

SUPPORTING COMMENTARY

Section A - AGREEMENT WITH FACILITIES PLAN

When reviewing the design plans and specifications, the evaluator must have a clear understanding of the facility plan and its relationship to the design. The design should conform as closely as possible to the facility plan. It is often necessary or desirable, however, to deviate from the facility plan as the project progresses. Deviation from the facility plan may be due to new information or to changes in regulatory requirements. The design and specifications package submitted for review should include a statement regarding agreement with the facility plan with emphasis given to those areas where the design deviates from the facility plan. When deviations from the facility plan are substantial, a re-evaluation of the plan, in whole or part, may be required.

A.1. MODIFICATIONS

Modifications to facility plans are often necessary, and may be the result of new information from pilot studies, detailed site investigations, or any one of a number of other sources. Changes in regulations, policies, and project goals between the time of facility plan preparation and the completion of design plans and specifications may also necessitate revision of the facility plan. When the facility plan is modified during the design process, the design engineer should prepare a full explanation and justification of the changes. This explanation and justification may take the form of a supplement to the facility plan or may be submitted as supporting material with the design plans and specifications.

Any modification to the facility plan must be evaluated to assess its effect on other criteria of the facility plan and on other treatment processes within the overall wastewater treatment-sludge management system. Particular care should be taken to insure that any effects on the wastewater treatment system are taken into account.

A.2. CHANGES IN REGULATIONS AND POLICIES CONSIDERED

In preparing the design plans and specifications, the design engineer should review the regulations and official policies relating to the sludge management project to determine if any changes since the preparation of the facility plan affect the design to the extent that modification of the facility plan is required. This review should cover, as a minimum, federal, state and local laws and regulations and local or regional land use plans.

Section B - SLUDGE TRANSPORT

Transport facilities must be designed to be compatible with the type and quantity of sludge produced at the treatment plant. The degree of processing prior to disposal will also affect the design of transport facilities. The mode of transport must be appropriate for the type of sludge and the ultimate disposal method. Local conditions and environmental features may play an important role in the design of sludge transport facilities and the selection of equipment.

B.1. SLUDGE CHARACTERISTICS

B.1.a. Quantity: Maximum, Average, Minimum

The quantity of sludge produced will determine the size of transport facilities. If equalization is included, the average quantity produced by the final unit process (dewatering, incineration, etc.) will be the determining factor in transport sizing; if not the peak quantity should be used. Staged items may be appropriate depending on the method of transport since some equipment is permanent and other equipment has a short service life.

B.1.b. Solids Content

The solids content is important in the design of auxiliary equipment as well as the details of the transfer equipment. It may be necessary to dilute very thick sludge for pipeline transport.

B.1.c. Odor Potential

Odorous or highly putrescible sludge can be a nuisance, particularly in cases where the transport distances or the transit times are long. Delays in transport of partially stabilized or conditioned sludge can create significant, highly objectional odor problems.

B.2. PIPELINE

Design of pipelines for transport of 0-4 percent sludge solids is essentially the same as for water or sewerage facilities(16). The key factors in pipeline design and providing adequate appurtenant facilities are described in the following sections.

B.2.a. Alternate Routes Considered

Preliminary design is used to reduce the number of potential pipeline routes. Generally, one route will be clearly favorable over the others, however, due to unknown or hidden conditions, a certain amount of flexibility should be maintained until final design is begun. Crossings can add significantly to the cost of the pipeline and to the complexity of construction

B.2.b. Distance

The length of the sludge pipeline can have a significant bearing on costs of the pipeline itself, on the pump station costs, and on the annual O&M costs. Sludge pipelines can be feasible for relatively short distances (approximately 5 miles) up to fairly long distances (100 miles).

B.2.c. Elevation Changes

In order to protect the pipeline from air binding due to entrapped air or from collapse due to vacuums which develop when pumps are stopped, air and vacuum relief valves should be provided at critical high points in the line.

B.2.d. Operating Program

A comparison use of constant versus variable speed pumps is important in determining the design flow through the pipeline. Variable speed pumps allow for continuous operation and lower storage requirements. Constant speed pumping will require more storage, for peak flow dampening by equalization, but is usually more efficient. The maximum and minimum velocities are an important consideration in pipeline design. For sludge transport 3 fps is a satisfactory value (16); slower rates can promote solids settling and decomposition, while higher rates cause scouring and increase head loss. Since pipelines represent a significant investment and have long service lives, they should be sized to permit efficient operation under existing conditions yet provide adequate capacity for future growth.

B.2.e. Pipe Selection

Sludge pipelines are generally cement-lined cast-iron or ductile iron pipe. Friction losses should be minimized since they can contribute significantly to the pumping requirements. Abrupt changes in slope and direction should be minimized as they introduce headloss for in excess of the loss through straight pipe. Depending on the nature of the sludge and the characteristics of the soil, corrosion-control features should be incorporated in the pipeline design.

B.2.f. Pumping Facilities

More than one pump station may be needed if the piping distance is long. The number of pump stations should be balanced with the size and number of pumps required for the most cost effective combination. Pumps should be appropriate for the type of sludge to be pumped and standby units must be provided.

B.2.g. Pipeline Cleaning Provisions

Pigging facilities, or an appropriate alternative, should be provided to allow for cleaning the sludge pipelines on a regular basis.

B.2.h. Emergency Operation

Storage for several days should be provided in case of equipment failure. Digesters can be used for this purpose if available. Standby power should be provided if there are not two independent sources of electricity to the pump stations. Additional storage may be substituted for standby power under certain conditions, although continuous operation is preferable.

B.2.i. Excavation Conditions Verified

Field tests should be used to establish or verify the subsurface soil conditions. Borings should be taken after the pipeline route has been established but prior to final design. The report should be used to isolate areas where special design considerations are needed. If highly unusual localized conditions exist, they should be avoided, if possible, or additional field tests made.

Existing or other planned underground utilities should be located and field verified if possible. If exact locations cannot be established, the contractor may be held responsible for locating them during design.

B.2.j. Methods of Right-of-Way Acquisition

Rights-of-way must be acquired for all pipelines. This process should be initiated in the early stages of the project. The preferable method is to obtain access rights on easements owned or controlled by other utilities or to negotiate with landowners. Condemnation is a lengthy, complex procedure which should be used only after all other methods fail.

B.3. TRUCKS

B.3.a. Alternate Routes Considered

It is often the case that several possible truck routes exist. The advantages and disadvantages of these must be examined before the final route is established. An alternative route should be planned to insure uninterrupted transport of sludge.

B.3.b. Haul Distance, Speed and Travel Time

The haul distance should be minimized to reduce travel time and the potential for accidents enroute to the disposal site. Topographic features may influence routing such that the shortest haul distance is not the most favorable. The practical limit is about 10 to 20 miles one-way, although in some special cases, hauls of up to 80 miles may be cost-effective.

Effective speed and travel time can be estimated from the haul instance, allowable speed of various segments of the route and the anticipated traffic conditions. In scheduling sludge hauling, activities during the day may affect the travel time; periods of heavy traffic should be avoided both from a safety standpoint and for efficiency of operation.

B.3.c. Compatibility of Proposed Route with Existing Road and Traffic

The existing conditions must be considered in the evaluation of truck transport. Physical constraints such as weight, height and speed limits may preclude truck transport and will definitely influence vehicle and route selection. Local traffic congestion and traffic controls will not only influence routing but should also be considered in determining the transport operation schedule. Public opinion on the use of local roadway, particularly residential streets may have a significant effect on truck transport operation.

B.3.d. Operating Schedule

An operating program must be outlined to insure efficient operation and adequacy of facilities. Realistic estimates of loading, unloading and round-trip haul times should be made. Daily maintenance of the trucks and other facilities must also be included in the working schedule. The trade-offs between longer working hours and more hauling equipment should be considered when scheduling sludge hauling.

B.3.e. Fuel Consumption

Fuel availability and costs can have a profound impact on the future of sludge hauling activities. Larger trucks tend to be more fuel efficient than smaller ones. Also, short haul distances over flat terrain will have lower fuel requirements than long distances and hills.

B.3.f. Manpower Requirements

Manpower requirements can be determined from the operating schedule. Truck drivers and mechanics as well as loading and unloading personnel will be required for an efficient sludge hauling operation (16).

B.3.g. Truck Selection and Acquisition

Truck selection is based on sludge type and quantity. The size, type and number of trucks must be specified. The useful life and long-term maintenance requirements of the vehicles should be considered in the selection of sludge transport trucks (16).

The trade-offs between purchase and lease should be evaluated before the method of acquisition is determined.

B.3.h. Contract Haul Considered

For small plants in particular, the possibility of contracting for periodic sludge hauling may be feasible. If such a program is undertaken, a contract and guarantee of reliable service will be required.

B.3.i. Facilities Required

Plant-site loading facilities should be accessible and in a convenient location. Depending on the type of sludge being hauled, hoppers or pipelines will be needed to load the trucks. Unloading is generally by gravity, either at a transfer station or directly on the land application site. Vehicle storage and a maintenance/repair shop should be located at the plant site. Washdown equipment and parking should be nearby.

Sludge storage facilities will be needed at the plant site. The capacity of these facilities will be influenced by the sludge unit processes and the reliability of the transfer system.

B.4. BARGE

The characteristics of a barge transport system are described in the following sections. These have been generalized and may not pertain to all barging operations.

B.4.a Haul Distance

The haul distance is an important parameter since it affects several aspects of operation.

B.4.b. Barge Speed and Travel Time

In planning a barge transport system, speed factors can play an important role. The traffic on the waterway; physical features, such as drawbridges, locks and height limitations; and natural characteristics such as currents and tides will all affect the speed of barge operation. Certain delays may be hard to judge, therefore travel time estimates should include a conservative safety factor.

B.4.c. Operating Schedule

An operating schedule should be developed taking the loading, unloading and round-trip travel times into consideration. This is critical when contracting for towing service.

B.4.d. Barge Selection, Acquisition and/or Tow Boat Acquisition

A major consideration in barge selection is the choice between towed or self-propelled. Other factors such as the size and number are related to the plant size and specific sludge processing system (16). The useful life of equipment will have a significant influence of the overall economics of the transport operation. The trade-offs between purchasing and leasing barges must be weighed. The final selection will depend on the size of the barges, use demands and service life. Depending on the frequency of barge towing, economics may favor purchase over lease of a tow boat. This is likely not warranted except for sizeable facilities with large quantities of sludge to be transported.

B.4.e. Contract Haul Considered

For moderate-sized operation, contract towing will most likely be the favored method of barge transport. For small operations with intermittent transport requirements, contracting for complete transport service may prove the most practical, efficient and economical. Contractual agreements should clearly define all services to be provided and include a barging schedule.

B.4.f. Manpower Requirements

The manpower requirements should be determined so that there is an adequate staff of properly trained individuals to carry out the sludge transfer and transport services.

B.4.g. Fuel Consumption

Unless self-propelled barges are used, the fuel use will be the responsibility of the towing company. In general, larger barges are more fuel efficient than smaller ones.

B.4.h. Facilities Required

Sludge loading and unloading will require pumping facilities and relatively short pipeline. Maintenance, fueling and cleaning facilities should be located near the loading dock. Storage requirements at the docking site will depend on the amount of storage at the processing site and on the reliability of the process and transport systems.

B.5. RAILROAD

Railroad transport is not common, therefore examples of existing systems are scarce. The following general guidelines should be modified to fit the particulars of the proposed railroad transport system.

B.5.a. Distance

The feasible haul distance for rail transport is dependent on the quantity of sludge transported, the cost of transportation and the value of sludge at the receiving end. Haul distance usually range from 50 to 150 miles.

B.5.b. Speed and Load-Limiting Factors and Travel Time

The speed of railroad transport will depend on the track conditions and traffic schedule. The limits on loads will determine the size and type of cars to be used. If the shipper is supplying cars, they will be required to meet the railroad's clearance limitations. The effective speed and travel time will depend on the railroad's operating schedule. Realistic estimates of travel time will be necessary to assess the suitability of the system for meeting transport needs.

B.5.c. Operating Schedule

An operating schedule based on loading time requirements and on the railroad's required travel time should be outlined during design to insure adequate transfer, transport and storage facilities.

B.5.d. Car Selection and Acquisition

The type, size and number of cars selected will depend on the type and quantity of sludge being transported and on the transport distance. The useful life of the cars and the frequency of maintenance will have an impact on the economics of the operation.

Tank cars are ordinarily supplied by the shipper. If liquid sludge is to be transported by rail, cars can either be purchased or leased from the manufacturer. Dump cars which would be needed for dewatered sludge are often owned by the railroad and available on a rental or fee basis.

B.5.e. Fuel Consumption

Fuel supply will be the responsibility of the railroad. Costs will be included in the transport charges.

B.5.f. Manpower Requirements

Staff will be required for loading and unloading the railroad cars and for a varying amount of maintenance, depending on type and ownership of the cars.

B.5.g. Facilities Required

Railroad sidings will be necessary at both the treatment facility and the disposal site. At the treatment plant, the siding could be designed in conjunction with the chemical delivery facilities. Loading and unloading facilities will depend on the type of sludge being transported and the ultimate disposal method. Car maintenance storage and cleaning will depend on the type and ownership of the cars.

B.6. ENVIRONMENTAL IMPACTS

The environmental impacts of the transport system should be clearly identified and mitigating measures designed to lessen any negative impacts. A certain amount of air pollution is associated with vehicular transport of sludge. Emission controls will minimize this potential. The impact of transport facilities on land use is minimal. Disruption from pipeline construction is short-term. Most routes can be restored to near their original condition in a relatively short time. A small amount of land will be dedicated to permanent use for transfer facilities. The impact of this is usually minor due to the remote location of most facilities. Of the methods available for sludge transport, barging has the greatest potential for having adverse effects on surface water. Accidental sludge spills which would cause surface water pollution should be guarded against. There is little danger that a groundwater supply would be adversely impacted by sludge transport.

Public acceptability of the transport method and route can have a profound effects on system operation. Safety features are important, particularly in congested areas where accidents are more likely to occur. The handling, transfer and transport of sludge can represent a certain health hazard; however, with adequate precautionary measures taken, this can be minimized. Sludge spills and the resultant human contact can be a health problem if not quickly attended to.

The financial impacts of sludge transport should be fully analyzed. Possible measures for reducing costs should be explored and implemented as practical. In the long run, a comprehensive maintenance program will reduce the general operating costs of the transport system and minimize unnecessary and expensive emergencies. Local historical and archaeological sites of significance identified in the facility plan should be protected. Care should be taken to minimize disruption of environmentally sensitive areas identified in the facility plan and to protect any endangered species in the vicinity. Such impacts are not usually significant in predisturbed areas such as treatment plant sites or pipeline rights-of-way.

B.7. REGULATIONS AND STANDARDS

The engineer must be cognizant of the regulations governing design and other local, state and federal standards which must be met. These must be followed throughout design and construction, and any conflicts resulting from overlapping jurisdictions must be resolved.

B.7.a. Surface Water Protection

Surface water quality must be maintained during construction and operation of all facilities. Federal standards have been set in P.L.92-500 and its amendments; local water quality standards may, however, be more rigorous and must be followed.

B.7.b. Sludge Loading and Unloading

Certain local regulations may govern the methods used for sludge transfer. Clean-up will be essential and there may be restrictions on the disposal of spilled sludge.

B.7.c. Construction Within Navigable Waterways

There are strict regulations regarding construction in navigable waters. These should be thoroughly examined during the preliminary stages of design. Often the waters are multi-jurisdictional, therefore, more than one agency will be approving plans and specifications and monitoring construction.

B.7.d. Building Codes

All local building codes and applicable employee health and safety requirements must be met by new construction projects. In addition, it may be required that existing facilities being modified comply fully to current codes.

B.7.e. Reporting Spills

Depending on local and state regulations, the reporting of sludge spills may be required. This is particularly important if such spills result in the violation of surface discharge regulations. The operating agency should be informed of the procedures for filing such a report.

B.7.f. Permits

All necessary permits for field studies, construction and operation should be identified early in the design stages. Procurement procedures should be initiated in sufficient time so that progress is not delayed because of the lack of proper permits and approvals.

Section C - LAND APPLICATION

C.1 SLUDGE CHARACTERISTICS

C.1.a. Type of Processing at Treatment Plant

Stabilization and dewatering processes impact the type of land application and equipment used as different equipment is used for liquid and dewatered sludges.

C.1.b. Quantity: Maximum, Average, Minimum

The average sludge quantity is necessary to determine the land application area requirements and in estimating the useful life of the site. Maximum quantities are required to determine equipment and storage facility capacities and to estimate daily operating schedules.

C.1.c. Analysis

The solids concentration affects the application equipment type and capacity. Particle or physical characteristics impact the soil conditioning value of the sludge. Volatile content is important for estimating the potential for developing odors while being stored or surface applied. The importance of heavy metals, pH, and nutrient content monitoring has been discussed in the facility planning section.

C.2. TYPE

The types of systems included below are crop utilization, dedicated disposal and land reclamation. Some areas may include a combination of two or three of these types of systems. A typical design for crop utilization is presented in Appendix A.

C.2.a. Crop Utilization

Crop utilization systems are designed to take advantage of the nutrient contents as well as the soil conditioning properties of the sludge. In the facilities plan a crop or crops were selected for utilization of sludge. These crops were selected for either their cash value, nitrogen or phosphoruous utilization rate, or their tolerance of heavy metals. This selection should be reviewed at the beginning of the design phase and adjusted if necessary. Along with the crop selection, individual tillage requirments should be determined. Grain crops such as corn require annual tillage. Other crops such as forages require tillage only when a new stand is desired (several years). The significance of determining tillage requirements is for costs and coordination with application operations so sludge incorporation can be completed simultaneously. In the case of a forage crop, incorporation is not possible except by an injector system. Therefore, applications on forage crops will usually be by surface systems unless an injection system can be used. The design should specify the application cycle in detail. Some crops such as forages can receive applications during the growth phase with a rest period just prior to harvest or grazing by animals. The rest period time depends on the frequency of rainfall or irrigation.

Liquid sludge is applied by spraying from a modified irrigation system, spraying from a truck, injection by tractor-towed system, injection by a truck mounted system or by a surface irrigation type system such as ridge and furrow or flooding. Dewatered sludge is usually applied by trucks with moving beds and spreading mechanisms or conventional agricultural manure spreaders.

C.2.b. Dedicated Disposal

Land application for disposal or dedicated disposal systems are similar to crop utilization systems except application rates exceed agronomic rates. Crops will not always grow well in these conditions and are generally not of major importance to system design. Application methods and tillage requirements are similar to those described above.

C.2.c. Land Reclamation

Land reclamation systems may be designed for future agricultural use, park land, residential development or commercial use. The design of the reclamation project will depend on the future use and conditions of land being reclaimed. If the site's future planned use is agricultural or residential, then heavy metal additions are a factor to be observed (Part I, Section F.6). Nitrate contamination of groundwater should be avoided. Surface application of dewatered-stabilized sludge can be left without incorporation allowing more of the ammonia to volatilize rather than nitrify, thus allowing somewhat higher application rates. The cumulative contaminant levels should be monitored if the site is to be used for agriculture, residential development, or parks.

The site should be analyzed to determine whether the soil is in poor condition due to natural causes or as a result of strip mining or some other man-made activity. Naturally occurring poor soils usually require more organic material and nutrients. Disturbed soils resulting from mining activities usually have low pH values and higher than normal concentrations of trace elements or heavy metals. Each site analysis should include these items. The analyses should also consider potential reactions of constituents in the ludge with constituents in the soil. The same application methods can be used for reclamation projects as used for crop utilization projects. Tillage requirements are the same as the other systems except possibly where loading rates are significantly higher than agronomic rates. In some instances deep plowing may be necessary instead of disking.

C 3. SITE CHARACTERISTICS

C.3.a. Topography

Extremely hilly areas may limit application equipment operation. Proper design should include slope determination to check if the application method will be operable. Site ground slopes should be determined and reviewed to develop erosion control practices. Even row crops such as corn may not be feasible on certain soils with high slopes. This problem can be minimized somewhat by contour planting or terracing.

C.3.b. Runoff Control

The design should include runoff control facilities containing or rerouting runoff from adjacent areas. These facilities may consist of small basins where runoff can be contained and allowed to percolate or evaporate. Another option would be to place a ditch along the affected area in order to route runoff elsewhere. A third option provides for use of existing drainways. The design should allow for buffer areas between application areas and drainways in order to minimize the possible contamination of drainage water. Provisions made for control of run off from liquid sludge applications should be designed for an emergency situation. Generally, if the system is being properly operated there should be no runoff created by liquid in the sludge. Runoff resulting from rainfall on the application site must be contained or controlled so that this runoff does not contaminate nearby surface water.

C.3.c. Soil

The soil characteristics at the proposed land application site should be typed and mapped. The pH and cation exchange capacity should be determined for each soil type. As discussed earlier these parameters impact the movement and possible plant uptake of heavy metals. Other parameters that are important to design are water intake rate, permeability, heavy metal concentrations, and texture.

C.3.d. Geohydrology

The groundwater aquifers underlying the land application site need to be delineated. The depth of the aquifer under varying conditions should be determined at several locations. Other characteristics such as the direction and rate of flow, the hydraulic gradient, the quality, and present and planned uses should also be established. The location of the primary recharge zones is critical in protecting quality.

The geologic formations underlying the land application site are important in establishing the design parameters. The type of bedrock; its depth, fractures, and surface outcroppings; and any faults are critical design factors.

C.4. DESIGN CRITERIA

C.4.a. Climate Factors

In order to determine application equipment sizing the designer should have included an estimate of the number of days when operations are not possible due to rainfall. Twenty-year records are preferred for analysis of rainfall data concerning agricultural operations. Wind velocity and direction is important in minimizing movement of aerosols and development of buffer areas to minimize the possibility of aerosols reaching neighboring property. This is a concern with spray type systems. Temperature variation is critical mainly with surface application during freezing weather when the ground is frozen or covered with snow. Unless special procedures are taken to avoid water pollution problems, surface application should be halted during these periods.

C.4.b. Loading Rates

C.4.b.(1) Metals - Design of crop utilization or reclamation systems should include a determination to prevent possible heavy metal buildup. The design should include the following items: background level of heavy metals (Pb, Zn, Cu, Ni, Cd); soil cation exchange capacity limits (see Table 9)

C.4.b.(2) Nitrogen - Crop utilization systems should include a determination of nitrogen forms present and an estimate of the mineralization rate. Additionally, the designer should have specified a procedure for confirming the actual mineralization rate (see Table 8 and Appendix A).

C.4.c. Crops

C.4.c.(1) Nutrient Uptake - The crop or crops chosen should be listed along with nitrogen, phosphorus, potassium, and micronutrient requirements for each. The table used for planning purposes should have been reviewed with the local farm advisor to see if local conditions will cause variations in the recommended quantities. (See Table 8 for typical values).

C.4.c.(2) Compatibility with Applications - Different crops are harvested in different ways at different times of the year. Land application systems must be designed with this in mind. Tillage requirements for incorporating surface applied sludge would interfer with growing a forage crop. Application schedules must be timed so as not to interfer with planting and harvesting. Each crop should be reviewed to determine if application can be made on the growing crop.

C.4.c.(3) Harvesting Requirement - Critical to both the application procedures and harvest operations is the timing and frequency of harvest. Some crops are harvested once a year with the plant removed completely or destroyed. Forage crops such as alfalfa are harvested several times a year with the plant base and root system left intact.

C.5. SYSTEM COMPONENTS

Within the treatment plant there are system components which impact application procedures or methods. These are discussed in the following sections. The design reviewer should be sure that the designer has developed compatible systems throughout (e.g. dewatered sludge can't be injected).

C.5.a. Dewatering

Dewatering designs or systems should be reviewed to determine percent solids achieved or expected and the chemicals used. Solids content will impact transport and application methods and costs.

C.5.b. Field Equipment

Field equipment should be designed to be compatible with crops. Any type of application equipment can be used for annual crops if the application is accomplished between harvest and planting. Spray injection systems are limited with forage crops. Also capacities must be designed for the expected number of days each year when application can actually take place. The field equipment design should be compatible with the moisture content of the sludge. Variation in moisture content can limit the type of equipment and impact costs of alternative types of equipment. Equipment should also be designed to acclimate to field conditions caused by climatic conditions. High flotation tires or tracked vehicles are often necessary to insure mobility.

C.5.c. Storage

Lagoon or pond storage systems are very economical to construct and maintain. The reviewer should analyze designs of these systems for adequate embankment protection. Covered storage is less common than open storage due to the higher cost. Covered storage or tank storage is preferred when storage areas are near residential areas. There are several potential nuisance conditions. They are odors, insect breeding, excessive weed growths on embankments, or vector breeding. Preventive methods should be included in the design. These include chemical addition facilities or aeration for odor control and proper design of embankment slopes and liquid depths to minimize the others.

C.5.d. Buffer Zones

Buffer zone size should be justified in the design. Applicable regulatory agency requirements should be reviewed. Spray systems require the largest buffer area (especially in windy areas) and injection systems the least. The designer should provide rationale for selection of the type of vegetation in the buffer zone. The type depends on the needs of the buffer area. Examples are shrubs for aesthetics, grass for erosion control, and trees for wind breaks. Fencing requirements depend on the surrounding land use. If the site is rural with privately owned land then a simple animal detainment fence may be sufficient. In an area near public accessible lands a chain link fence may be necessary.

C.6. MONITORING

C.6.a. Land

Soils monitoring may include pH, CEC, nitrogen, phosphorus, potassium, and heavy metals (Cd, Cu, Zn, Pb, Ni). The nutrient analyses are useful for good crop growth and for preventing excessive amounts of nitrogen or phosphorus in succeeding applications or for determining additional nutrient needs. Potassium is not normally a problem but monitoring is necessary to determine additional needs for good crop growth. The pH, CEC and metals determinations are useful for preventing metals accumulations in soils or crops. Pathogen monitoring should be as specified by the regulatory agency.

C.6.b. Crops

Crop monitoring should include yield, crop disease, and crop pest evaluations. Tissue analysis may be required periodically for food-chain crops. Crops destined for human consumption should be monitored for pathogens.

C.6.c. Water Quality

Surface waters and intermittent streams (when flowing) should be monitored as required by the appropriate regulatory agencies. Monitoring points should include at least one sampling station upstream of the application area and one downstream from the application area. Frequencies depend on circumstances of each site. Minimum parameters include BOD_5, suspended solids, nutrients, and coliforms. Nearby domestic wells should be tested prior to project startup and then monitored periodically. On-site monitoring wells should be placed and sampled as required by the appropriate regulatory agency. At a minimum, tests should include nitrates, total dissolved solids and coliforms.

C.7. RELIABILITY AND FLEXIBILITY

Reliability is normally provided by extra storage facilities. Some systems may have standby equipment and/or a good spare parts inventory. Designs should identify potential application areas for future expansion, and operational flexibility. Flexibility may be attained by converting a crop growing area to a disposal area or switching to a different type of crop. This may allow greater loading rates. The design should consider this option. The decision for determining the proper amount of standby equipment should be justified in the design. Standby tractor or trucks can be very costly and may not be necessary if the right spare parts inventory is maintained.

Section D - LANDFILL

The design of a sludge landfill depends on many interrelated factors. These will be addressed in the following sections. For more detail regarding these areas, the evaluator is referred to Process Design Manual for Municipal Sludge Landfills (34). An example landfill design calculation is given in Appendix B.

D.1. SLUDGE CHARACTERISTICS

The first step in landfill design is to clearly define certain sludge characteristics.

D.1.a. Type of Processing at Treatment Plant

Stabilization and dewatering processes effect the type oflandfill and the daily quantity of sludge that can be accepted.

D.1.b. Quantity: Maximum, Average, Minimum

The sludge quantity is necessary in establishing the landfill area requirements and in estimating the useful life of the site. The average quantity will prove most useful for this purpose. Maximum sludge quantities will be needed to size equipment and storage facilities and for determining daily operating schedules.

D.1.c. Analysis

The solids content or concentration of sludge is related to the nature of wastewater treatment and to the sludge processing steps. The type and operation of dewatering equipment has, perhaps, the most significant effect on the sludge concentration. A certain degree of flexibility should be incorporated in the design of landfills to compensate for the variability in dewatered sludge. Volatile solids content of the sludge determines the gas produced and the long term volume reduction of solids. Typically the volatile portion of sludge ranges from 30 to 80 percent. Gas is generated at 16 to 18 ft^3/lb volatile solids destroyed(34). Almost all the volatile solids will eventually be destroyed. The nitrogen found in sludge represents a potential source of groundwater pollution. The total quantity of nitrogen as well as the species present are of importance. Nitrate is the principal species of concern and is relatively mobile in soil. It is conservative to assume that all of the nitrogen forms present will eventually be oxidized to nitrate. Inorganic ions such as heavy metals are found in most municipal sludge. These can be leached if soil and sludge are acidic. If near neutral conditions can be maintained, the metals will not be as readily leached from the sludge. Most sludge treatment processes reduce the number of pathogens and the possibility of pathogenic contamination associated with sludge landfilling (34), but do not provide a sterile product. Toxic organic compounds can present a potential contamination problem. These should be identified and dealt with according to their nature and the disposal methods employed.

D.2. REGULATIONS AND STANDARDS

Consideration must be given to requirements governing the degree of sludge stabilization, the loading rates, the frequency and depth of cover, monitoring and reporting. The design should conform to all building codes and should include adequate buffer zones to protect public roads, private structures and surface waters.

Obtaining permits for construction and operation of sludge landfills can be a long and costly process. The following is a partial list of the permits which may be required:

- NPDES permit-if landfill is in wetlands
- Army Corps of Engineers permit-for construction of levee, dike or containment structure to be placed in the water in a wetlands area
- Office of Endangered Species permit-if landfill is located in critical habitual of an endangered species
- Solid Waste Management permit
- Special Use permit
- Sedimentation Control permit

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- Solid Waste Management permit
- Special Use permit
- Sedimentation Control permit

- Highway Department permit
- Construction permit
- Building permit

D.3. SITE CHARACTERISTICS

The definition of site characteristics is essential to the design of the landfill. These should be clearly described and analyzed to insure the suitability of the site and the method of landfilling.

D.3.a Site Plan

The site plan should contain the following information as a minimum

- Boundaries of fill area and buffer zones
- Topographic features and slopes of fill area and buffer zones
- Location of surface water, roads, and utilities
- Existing and proposed structures and access roads

- Existing vegetation to remain and to be removed; areas to be re-vegetated.

D.3.b. Soils

The soil characteristics at the landfill site should be thoroughly catalogued and mapped. The information of most importance to the design and operation of the landfill includes depth, texture, structure, bulk density, porosity, permeability, moisture, stability, and ease of excavation. The pH and cation capacity have a direct bearing on heavy metal transport through the soil; these must be considered to insure protection of surface and groundwater supplies.

D.3.c. Geohydrology

The groundwater aquifers underlying the landfill site need to be delineated. The depth of the aquifer under varying conditions should be determined at several locations. Other characteristics such as the direction and rate of flow, the hydraulic gradient, the quality, and present and planned uses should also be established. The location of the primary recharge zones is critical in protecting quality.

The geologic formations underlying the landfill are important in establishing the design parameters. The type of bedrock; its depth, fractures, and surface outcroppings; and any faults are critical design features.

D.3.d. Climate

The climate influences many factors in the design of landfills. It plays a part in the rate of organic decomposition, the composition and quantity of leachate and runoff and the day-to-day fill operations. Information such as seasonal temperature, precipitation, evapotranspiration, number of freezing days, and wind direction and speed can be obtained from a local weather station.

D.3.e. Land Use

The present and proposed use of the landfill site and adjacent properties will have a decisive influence on the mitigating measures taken to reduce any adverse impacts of the project. If the site is already dedicated to refuse or sludge disposal it is unlikely that expanding it will result in adverse impacts. However, if it is located in or near a populated area, extensive measures may be needed to justify the proposed use and maintain the value of adjacent properties.

D.4. LANDFILL TYPE

There are three basic types of landfill for sludge. These are sludge only trench fill, sludge only-area fill and co-disposal with refuse. The conditions for which each are best suited are given in Table 11.

TABLE 11. SLUDGE AND SITE CONDITIONS (34)

Method	Sludge solids content	Sludge characteristics	Hydrogeology	Ground slope
Narrow trench	15-28%	Unstabilized or stabilized	Deep groundwater and bedrock	<20%
Wide trench	≥20%	Unstabilized or stabilized	Deep groundwater and bedrock	<10%
Area fill mound	≥20%	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as level area is prepared for mounding
Area fill layer	≥15%	Unstabilized or stabilized	Shallow groundwater or bedrock	Suitable for medium slopes but level ground preferred
Diked containment	≥20%	Stabilized	Shallow groundwater or bedrock	Suitable for steep terrain as long as a level area is prepared inside dikes
Sludge/refuse mixture	≥3%	Unstabilized or stabilized	Deep or shallow groundwater or bedrock	<30%
Sludge/soil mixture	≥20%	Stabilized	Deep or shallow groundwater or bedrock	<5%

D.5. LANDFILL DESIGN

Typical design criteria for the three methods of landfill disposal are given in Table 12.

D.6. FACILITIES

Various ancillary facilities will be needed at the landfill site. These are described in the following sections. It should be noted that all of these may not be needed at every site.

D.6.a. Leachate Controls

Leachate from the landfill must be contained and disposed of if it poses a threat to public health or represents a potential source of water pollution. Numerous methods are available for controlling leachate including drainage, natural attenuation, soil or membrane liners, or collection and treatment. The method chosen and the design features are specific for each project.

D.6.b. Gas Control

Gas produced by the decomposition of organic matter can present a potential danger, particularly if the landfill is located near a populated area. Methane gas, in particular, is highly explosive if confined in an enclosed area.

Some method for venting the gases produced at the landfill must be provided. The two types widely accepted are the permeable and impermeable. Permeable methods usually consist of a gravel filled trench around the fill area to intercept migrating gas and vent it to the atmosphere. Impermeable methods consist of placing a barrier of low permeability material, such as compacted clay, around the fill area to minimize lateral movement of gas. In general, methane recovery is not economically cost-effective at sludge only or small co-disposal sites.

Additional information dealing with the design of gas controls is presented in reference 34.

D.6.c. Roads

Access and on-site roads are necessary at the landfill site. Access roads and permanent on-site roads should be paved; temporary roads may be constructed of well compacted natural soil. For loaded vehicles uphill grades should be less than 7 percent and downhill grades less than 10 percent. Radii should be suitable for the trucks which are to use the roads.

TABLE 12. LANDFILL DESIGN CRITERIA (34)

Method	Sludge solids content, percent	Trench width, ft	Bulking required	Bulking agent	Bulking ratio[1]	Cover Thickness, ft Interim	Cover Thickness, ft Final	Imported soil required	Sludge application rate, cu yd/ac (in actual fill areas)	Equipment
Sludge only-trench fill										
Narrow trench	15-20 20-28	2-3 3-10	No[2] No[2]	--- ---	---	------ ------	2-3 ft 3-4 ft	No	1,200-5,600	Backhoe with loader excavator, trenching machine
Wide trench	20-28 ≥28	10 10	No[2] No[3]	--- ---	---	------	3-4 ft 4-5 ft	No	3,200-14,500	Track loader, dragline, scraper, track dozer
Sludge only-area fill										
Area fill mound	≥20	---	Yes[3]	Soil	0.5-1 soil 1 sludge	3 ft	3-5 ft	Yes	3,000-14,000	Track loader, backhoe with loader, track dozer
Area fill layer	≥15	---	Yes[3]	Soil	0.25-1 soil: sludge	0.5-1 ft	2-4 ft	Yes	2,000-9,000	Track dozer, grader, track loader
Diked containment	20-28 ≥28	--- ---	No[2],[4] No[3],[4]	Soil Soil	0.25-0.5 soil: 1 sludge		3-4 ft	Yes	4,800-15,000	Dragline, track dozer, scraper
Co-disposal with refuse										
Sludge/refuse mixture	≥3	---	Yes[3]	Refuse	4-7 tons refuse: 1 wet ton sludge	0.5-1 ft	2 ft	No	500-4,200	Dragline, track loader
Sludge/soil mixture	≥20	---	Yes	Soil	1 soil: 1 sludge	0.5-1 ft	2 ft	No	1,600	Tractor with disc, grader, track loader

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[1] Volume basis unless otherwise noted

[2] Land-based equipment

[3] Sludge-based equipment

[4] But sometimes used

1 ft = 0.305 m

1 yd^3 = 0.765 m^3

1 acre = 0.405 ha

D.6.d. Soil Stockpiles

If insufficient or inappropriate soil at the landfill site warrants importation of soil, a storage place should be located on-site. The quantity and type of soil to be stockpiled will depend on the individual demands of the landfill. Stockpiles may also be desirable for winter operations in cold climates where frozen ground may limit excavation of cover or bulking materials.

D.6.e. Inclement Weather Areas

Special work areas should be provided so that landfilling operations may be continued even during inclement weather. It is most convenient to locate these near the entrance to the site and to provide paved or all-weather roads around them.

D.6.f. Minor Facilities

An office and other employee facilities should be provided at the landfill site. For larger operations a permanent structure should be provided, while at smaller sites a trailer might suffice. An equipment barn and shop may be desirable in areas where weather is inclement.

Larger landfills should have electrical, water, communication and sanitary services; for remote facilities, this may mean extending existing utilities. Chemical toilets, bottled water and on-site electrical generation may reduce the cost of obtaining services from the utility companies.

To protect the landfill site and the general public, the site should be fenced. Access should be limited to one or two entrances secured with gates. The height and type of fence provided should be chosen to suit local conditions. A 6-ft chain link fence topped with barbed wire will restrict trespassers; a wood fence or hedge is effective in screening the operation from view; and a 4-ft barbed wire fence will keep livestock from the site. Portable lighting is effective if landfill operations are carried out at night. Permanent lights should be provided for all structures and heavily used access roads. A cleaning program will be necessary for equipment in frequent contact with sludge. A curbed wash pad and collection basin should be provided to contain the contaminated wash water so that it can be treated. Groundwater monitoring is crucial and should not be overlooked. The number, type and location of monitoring wells must be suited to the specific conditions associated with the landfill. Depending on the size and location of the landfill, landscaping may be an important design factor. The aesthetic acceptability of the landfill is critical if it is in or near an urban or densely populated area. In general, plants should be low maintenance types which will quickly become an effective visual barrier.

Depending on the size and location of the landfill, on-site equipment facilities may be warranted.

D.7. LANDFILL EQUIPMENT

A wide variety of equipment is required for a sludge landfill. The type of equipment depends on the landfill method employed and on the quantity of sludge to be disposed of. Equipment will be needed for sludge handling, excavation, backfilling, grading and road construction. Table 13 presents typical equipment performance characteristics for various methods of sludge landfilling.

D.8. MANPOWER REQUIREMENTS

For effective operation, landfill operations must be staffed by well-trained, qualified personnel. Typical positions include equipment operators, a superintendent/foreman/supervisor, mechanics and laborers. The size of the staff will depend on the type of landfill and the operating schedule.

D.9. FLEXIBILITY AND RELIABILITY

Due to the possibility of changes in sludge characteristics and quantities, a landfill site should be designed with a maximum degree of flexibility. Since the life of a landfill is difficult to predict accurately expansion may be needed sooner than originally planned or it be delayed for various reasons. Any change in wastewater treatment or sludge handling may affect the nature and quantity of sludge produced. If this is drastic, operational modifications may be needed. The landfill should be designed so that such changes can be made without major disruption to operations.

Reliability is also an important factor in designing a landfill operation. Continunity of operation should not be stopped because of inclement weather unless absolutely necessary. In such cases, special work areas and storage facilities should be available. Adequate back-up equipment should be available on-site or nearby for emergency operations or unexpected equipment failures.

D.10. ENVIRONMENTAL IMPACTS

The specific areas of environmental impact will vary among landfill locations. However, crucial impact areas normally include land use; air, surface water and groundwater quality; social, health and economics; historical and archaeological sites and habitats of endangered species. Adverse impacts should be mitigated by the measures suggested in the facilities plan. These mitigating measures should be definitive and included as features of the design.

Section E - COMBUSTION

Combustion systems are usually designed with the close cooperation and assistance of one or more manufacturer of combustion equipment. Most design criteria and procedures available relate specifically to one manufacturer of the type of equipment in question. The similarities between manufacturers are such that

TABLE 13. LANDFILL EQUIPMENT PERFORMANCE CHARACTERISTICS (34)

	Trench				Area fill													Codisposal					
	Narrow trench		Wide trench		Mound					Layer					Diked contain-ment			Sludge/ refuse		Sludge/ soil			
Equipment name	Trench construction	Covering	Trench construction	Covering	Soil hauling	Mixing	Sludge hauling	Mounding	Covering	Soil Hauling	Mixing	Sludge hauling	Layering	Covering	Soil hauling	Dike construction	Covering	Spreading	Covering	Sludge spreading	Mixing	Hauling	Covering
Trenching machine	G	G	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Backhoe with loader	G	G	-	-	F	F	F	G	F	F	F	F	-	-	F	-	-	-	-	-	-	-	-
Excavator	G	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Track loader	-	G	G	F	F	G	F	G	G	F	G	F	F	F	F	F	-	F	F	F	-	G	F
Wheel loader	-	G	F	-	G	F	G	F	F	G	G	G	-	-	G	F	-	-	-	-	-	F	F
Track dozer[a]	-	G	G	G	-	G	-	F	G	-	G	-	G	G	-	G	G	G	G	G	F	-	G
Scraper	-	-	G	-	G	-	F	-	-	G	-	F	G	G	G	G	-	-	F	-	-	F	F
Dragline	G	G	G	G	-	-	-	-	G	-	-	-	-	-	-	-	G	-	-	-	-	-	-
Grader	-	-	-	-	-	-	-	-	-	-	-	-	G	G	-	-	-	-	-	F	-	-	-
Tractor with disc	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	G	-	-

LEGEND

G - Good. Fully capable of performing function listed. Equipment could be selected solely on basis of function listed.

F = Fair. Marginally capable of performing function listed. Equipment should be selected on basis of full capabilities in other function.

- = Not applicable. Cannot be used for function listed.

a Caterpillar D-6 generally is the largest track dozer appropriate for a sludge landfill.

generalities can be drawn which will aid the evaluator in determining the reasonableness of a particular design.

E.1. SLUDGE CHARACTERISTICS

The characteristics of the sludge which have the greatest impact on the design of combustion systems are the quantity, moisture content, and heat value. Other characteristics which will have an effect on the potential for air pollution are the nitrogen, sulfur, heavy metals (lead and mercury) and toxic organic compounds.

E.1.a. Type of Processing at Treatment Plant

The type of prior processing at the plant will determine the sludge characteristics to the combustion process. The stabilization process, if any, will influence the volatile solids/heat content. The dewatering process will determine the solids content of the sludge. If pressure filters or vacuum filters are used for dewatering large quantities of non-volatile inorganic chemicals may be added. The design of the prior processing deserves as much consideration as the design of the combustion process. Any failure of the prior processing to provide the design sludge characteristics will also cause failure of the combustion process.

E.1.b. Quantity: Maximum, Average, Minimum

The quantity of sludge produced will determine size of the combustion process equipment. Typically, the combustion process will not be designed for peak sludge production, but for some quantity between peak and average production, with storage provided to make up the difference. A portion of this storage may be in the sludge process unit processes. Care must be taken that any septic conditions which may occur in sludge storage are adequately considered. Sludge quantity estimates must take into account the mass of chemicals added in the conditioning and dewatering processes.

E.1.c. Analysis

The sludge solids and heat content will, together with sludge quantities, determine the size and fuel and air requirements of the combustion process. The solids and heat contents should be experimentally determined, whenever possible, but where necessary there have been several formulae, with varying accuracies, developed for heat content estimates (10, 12, 13). In making heat content estimates, the masses and heats of the reactions of the conditioning chemicals must be considered.

Sulfur affects the heat content of the sludge, and is also important in determining the sludge's potential for air pollution. Additional possible air pollutants are heavy metals, especially mercury and lead, and persistent toxic organic compounds such as pesticides and polychlorinated biphenyls.

E.2. REGULATIONS AND STANDARDS

Federal, state and local air quality requirements must be met by the combustion process design. Permits and standards relating to ash disposal will be discussed under the sections for the respective disposal methods.

E.2.a. Air Quality Requirements

The federal "New Source Performance Standards for Sewage Sludge Incinerators" (64) establishes the following limitations for particulate emissions:

1. No more than 0.65 g/kg dry sludge input 1.30 lb/ton dry sludge input
2. Less than 20 percent opacity, except where opacity is due to uncombined water

The EPA has also established a limitation of 3,200 g/day for mercury emissions in the Amendments to the National Emission Standards (47).

If PCB's exceed 25 mg/kg dry sludge, 95 percent destruction must be assured by the design of the incinerators. Additional regulations are being developed under the Toxic Substances Control Act (63) and the Resource Conservation and Recovery Act (2) which should be consulted in designing the sludge incineration system.

Many states, regional authorities, and local governments have established emission limitations more stringent than the federal regulations. In addition to more restrictive particulate, opacity, mercury, and PCB requirements, other limitations may be imposed on emissions, such as:

- Oxides of nitrogen
- Sulfur dioxide
- Carbon monoxide
- Heavy metals, especially lead
- Persistent organic compounds, such as pesticides
- Hydrocarbons and carbonyls

In general, a properly designed and operated sludge combustion process will have little difficulty in meeting emission standards.

E.2.b. Permits

All appropriate federal, state, regional and local permits, licenses and approvals should have been identified and obtained or applied for by the time of design review. The ambient air standards in the vicinity of the combustion sytem must also be considered.

E.3. MULTIPLE HEARTH INCINERATION OR PYROLYSIS

A description of these processes is given in Part I, Section H.1.

E.3.a. Operating Schedule

The operating schedule will affect the sizing of all components after the final sludge storage tank. Eight-hour-a-day, five-day-a-week operations are possible but not practical because they require three to four times the equipment of continuous operations and are also costly to maintain at operating temperature with no sludge feed (67).

E.3.b. Reactor Design

In designing the reactor, the key parameter is hearth loading rate. Values of 6 to 12 lbs/sq ft/hr on a total wet sludge basis (68) and 1.47 to 3.32 lb/sq ft/hr on dry solids basis (67). Table 14 illustrates several typical wet sludge loading rates and Figure 12 is a plot of hearth area vs. design capacity on a dry solids basis for several actual installations.

The number of hearths, reactor dimensions, and rabble speed will be established from the incinerator manufacturer's data. Table 15 is a summary of the standard furnace dimensions available from one of the major manufacturers. Current practice favors 5 to 12 hearths for sewage sludge incineration (67). In addition, the heaviest wall thickness available is generally recommended (69).

Typical center shaft and rabble arm cooling air flows as function of wet sludge flow for several operating incinerators are shown in Figure 13.

The sludge feed system should be designed for the maximum anticipated charging rate and should include a sludge weighing or metering device. Where pyrolysis is to be practiced, the sludge feed system should be designed to minimize the entry of air through the charging port.

E.3.c. Auxiliary Fuel System

The auxiliary fuel requirements fall into three categories: start-up, continuous operation and standby. The fuel supply system must have sufficient capacity at the greatest of those three rates. Substantial quantities of auxiliary fuel are always required to bring a multiple hearth furnace up to the required temperatures for sludge ignition. In addition, these heat-ups, and cool-downs, must be at very slow rates, typically 20 to 25 F°/hr for large incinerators, 150 F°/hr for very small incinerators, for temperature changes from 70°F to 1500°F. Figure 14 illustrates typical heat-up and standby fuel consumption rates as a function of hearth area. The fuel consumption rate for continuous operation will be established by the mass and energy balance calculations. Standby fuel is that fuel required to maintain the furnace at a constant, slightly reduced, temperature during periods in which no sludge is fed.

TABLE 14. MULTIPLE HEARTH FURNACE LOADING RATES

Type of sludge	Solids %	Volatile solids, %	Chemical concentration,* mg/l	Typical wet sludge loading rate,** lb/hr/sq ft
1. Primary	30	60	N/A	7.0-12.0
2. Primary + $FeCl_3$	16	47	20	6.0-10.0
3. Primary + low lime	35	45	298	8.0-12.0
4. Primary + WAS	16	69	N/A	6.0-10.0
5. Primary + (WAS + $FeCl_3$)	20	54	20	6.5-11.0
6. (Primary + $FeCl_3$) + WAS	16	53	20	6.0-10.0
7. WAS	16	80	N/A	6.0-10.0
8. WAS + $FeCl_3$	16	50	20	6.0-10.0
9. Digested primary	30	43	N/A	7.0-12.0

* Assumes no dewatering chemicals.

** Low number is applicable to small plants, high number is applicable to large plants.

The data in this table developed from manufacturers' information.

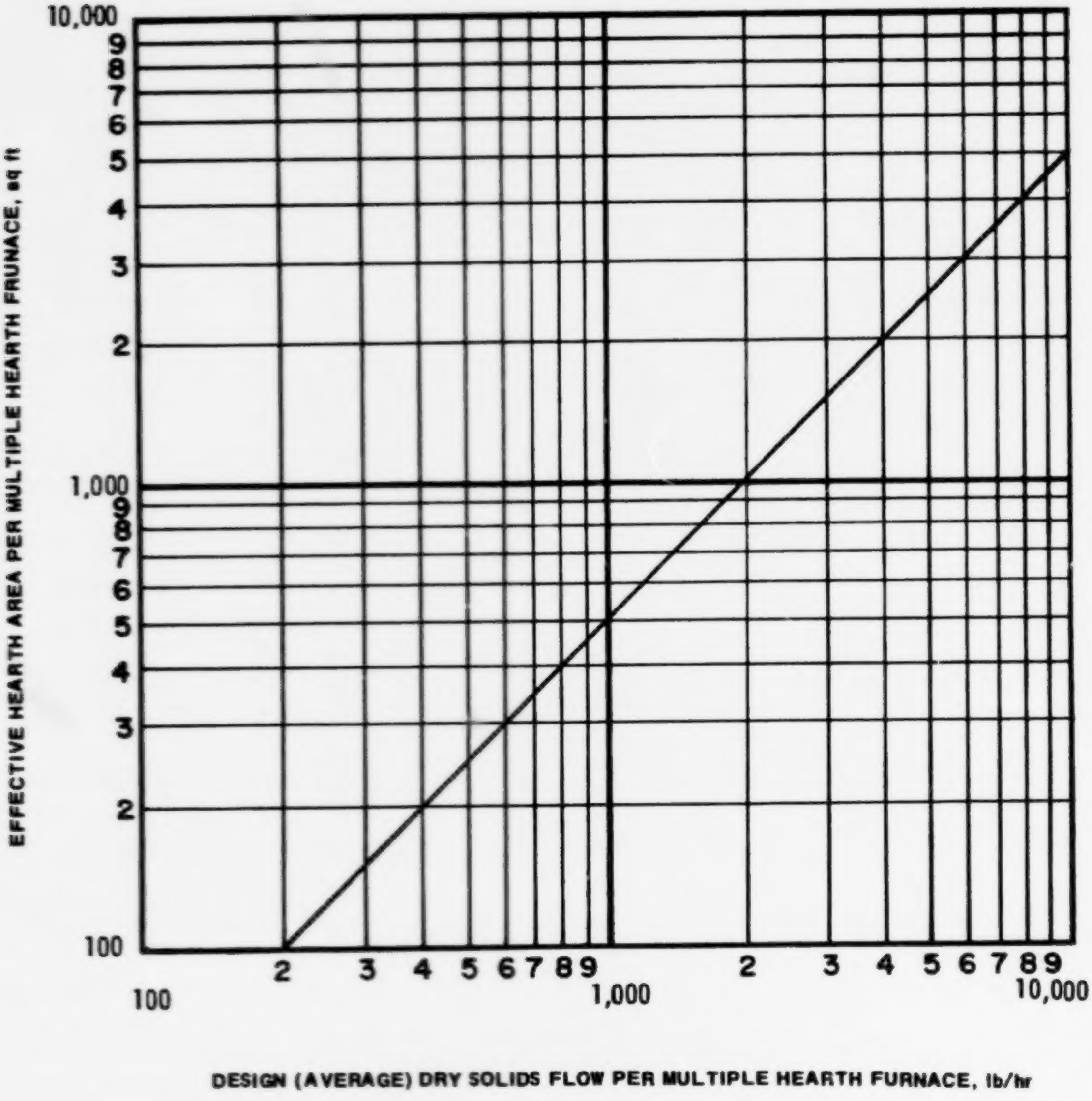


Figure 12. Multiple hearth furnace hearth area vs. design capacity. (from data in Reference 67)

TABLE 15. TYPICAL SIZES OF MULTIPLE HEARTH FURNACE UNITS (67)

Effective hearth area, sq ft	Outer diameter, ft	Number hearths	Effective hearth area, sq ft	Outer diameter, ft	Number hearths
85	6.75	6	988	16.75	7
98	6.75	7	1041	14.25	11
112	6.75	8	1068	18.75	6
125	7.75	6	1117	16.75	8
126	6.75	9	1128	14.25	12
140	6.75	10	1249	18.75	7
145	7.75	7	1260	16.75	9
166	7.75	8	1268	20.25	6
187	7.75	9	1400	16.75	10
193	9.25	6	1410	18.75	8
208	7.75	10	1483	20.25	7
225	9.25	7	1540	16.75	11
256	9.25	8	1580	22.25	6
276	10.75	6	1591	18.75	9
288	9.25	9	1660	20.25	8
319	9.25	10	1675	16.75	12
323	10.75	7	1752	18.75	10
351	9.25	11	1849	22.25	7
364	10.75	8	1875	20.25	9
383	9.25	12	1933	18.75	11
411	10.75	9	2060	20.25	10
452	10.75	10	2084	22.25	8
510	10.75	11	2090	18.75	12
560	10.75	12	2275	20.25	11
575	14.25	6	2350	22.25	9
672	14.25	7	2464	20.25	12
760	14.25	8	2600	22.25	10
845	16.75	6	2860	22.25	11
857	14.25	9	3120	22.25	12
944	14.25	10			

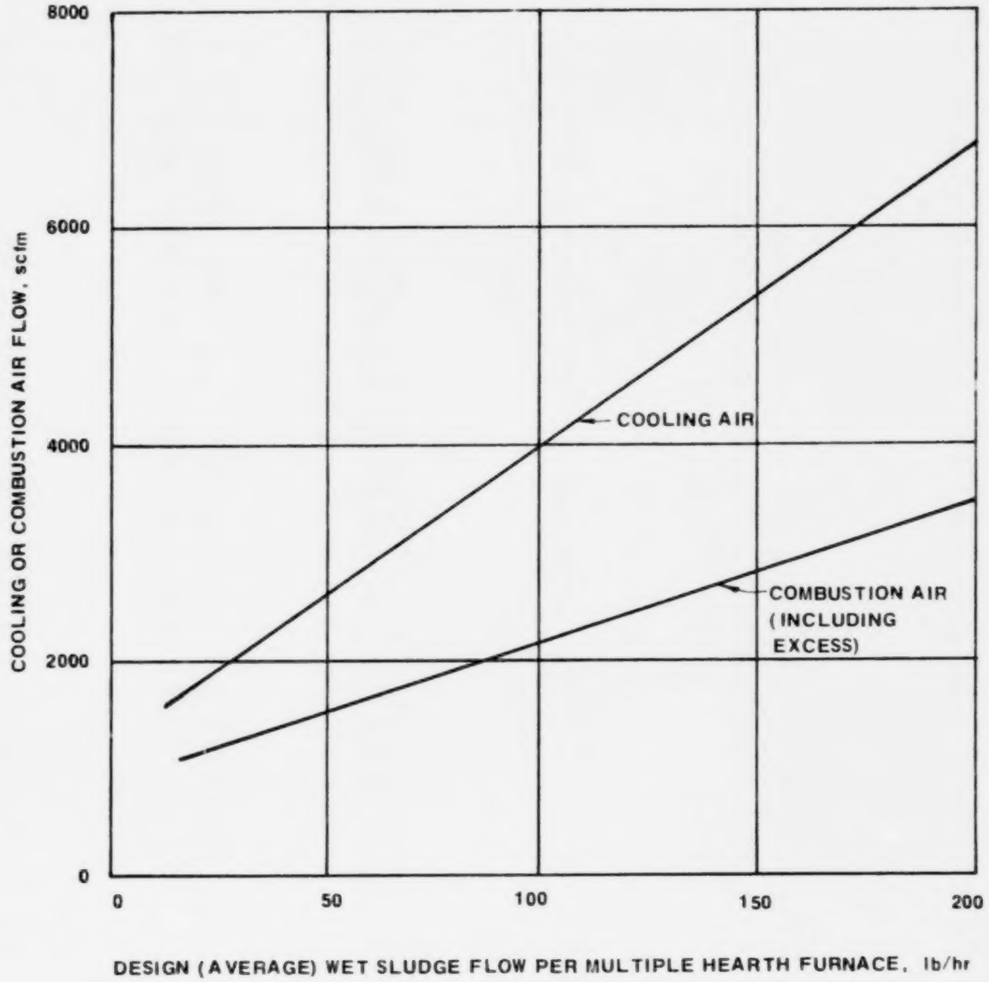


Figure 13. Multiple hearth air supply vs. design capacity. (From data in reference 67)

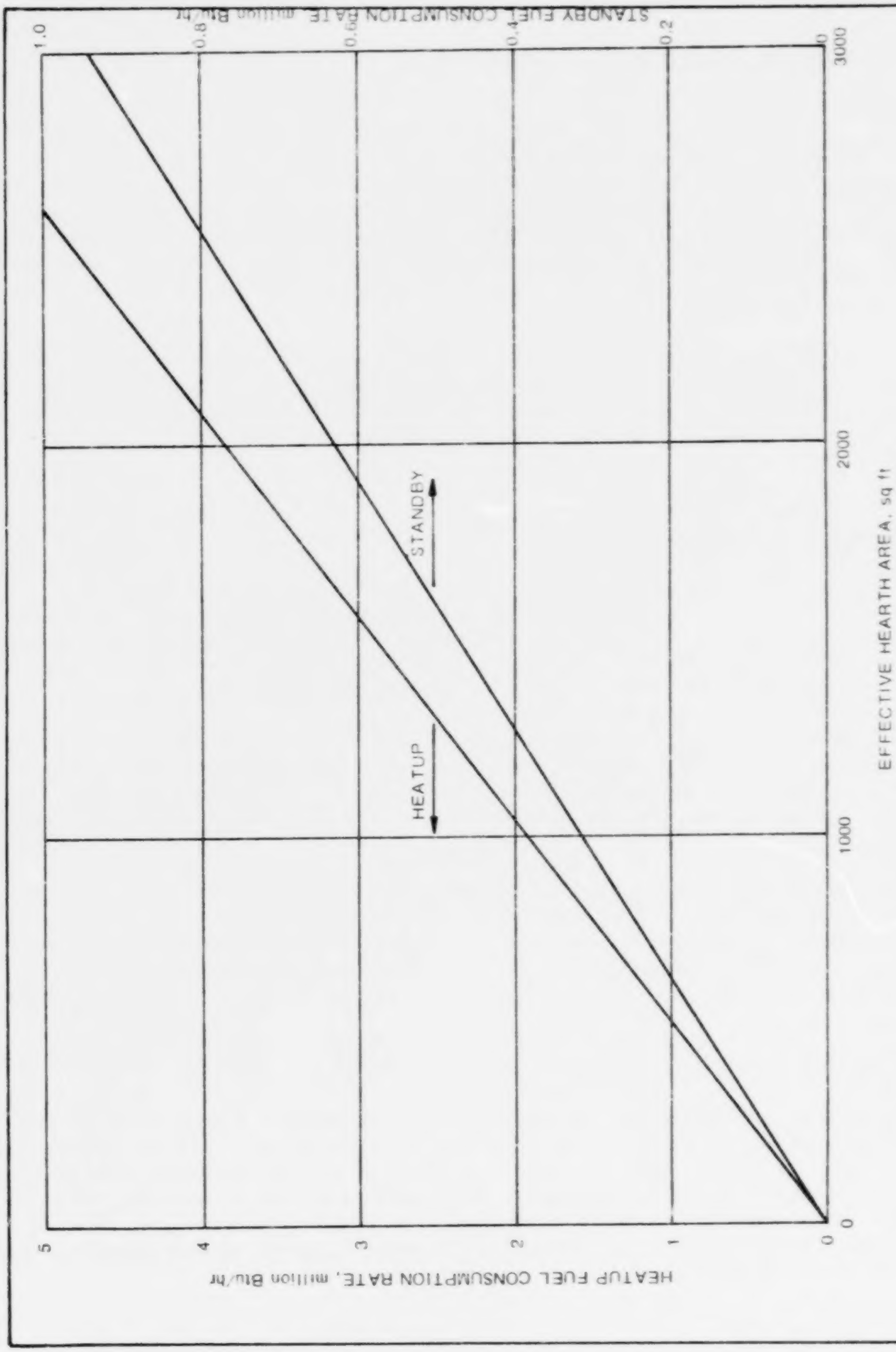


Figure 14. Multiple hearth furnace heatup and standby fuel consumption rate. (67)

E.3.d. Combustion and Excess Air Requirements

E.3.d.(1) Incineration - The exact combustion air requirement is determined from the theoretical oxygen demand (THOD) of the sludge and auxiliary fuel. Air is approximately 21 percent oxygen, so the actual air requirement would be (100/21) (THOD). Operating experience has shown that excess air is required for complete combustion, usually on the order of 75 to 200 percent of the theoretical requirement. Assuming 100 percent excess air, then, the actual air requirement would be (200/21)(THOD). Figure 13 illustrates typical combustion air supplies as a function of dry solids feed.

E.3.d.(2) Pyrolysis - True pyrolysis is fractional distillation where all heat is applied externally to the reactor and no oxygen is introduced. Pyrolysis, as proposed for multiple hearth reactors, is starved oxygen combustion, wherein a portion of the pyrolysis products are burned within the reactor as the heat source for the reaction.

E.3.e. Incineration Ash Systems

The design of incinerators must include adequate facilities for handling and disposing of incinerator ash. Ash handling and disposal systems should be sized for the maximum anticipated ash flow, or sufficient storage provided to permit lesser capacities. The design of the ash handling and disposal systems should take into account the potential for dust problems which ash disposal presents.

E.3.e.(1) Handling - Ash is usually transported by truck or by slurry pipeline to the disposal site. The slurry operation is often combined with a quenching operation to cool ash discharged from the incinerator. Dewatering requirements should be considered for any ash transported in a slurry form, either by truck or pipeline.

E.3.e.(2) Disposal - Ash is usually disposed of by landfilling or lagooning of a slurry. Land application is technically feasible but is not being practiced as it is not generally considered to offer any advantages. Ash has been used as an amendment for road subgrades to improve freeze-thaw characteristics, as a building material additive, and as a quasi-fertilizer for its phosphate content.

E.3.f. Pyrolysis Residue Systems

Where pyrolysis is practiced, the design of the combustion process must include systems for handling and utilizing or disposing of residues. All of the residues may have value as fuels, and if their use or sale is contemplated, the handling system should maximize their recovery. Pyrolysis char is of dubious value as a fuel, and may lend itself best to disposal by landfill. Handling systems and utilization should take into account the corrosive natures of the gases and tars, as well as their relatively low rank as fuels.

E.3.g. Air Quality Control

After-burners are used for odor control, hydrocarbon and carbonyl destruction, and for persistent toxic organic compound destruction. Scrubbers of various types and electrostatic precipitators are used for particulate removal. The electrostatic precipitator is more efficient, but is more costly. The design of air quality control equipment should be based on the actual volume of gases expected to pass through the stack at the actual stack exhaust temperature. Equipment design should consider the corrosive nature of stack gases.

Wet Venturi scrubbers are the most common type. The stack gases are passed through a reduced cross sectional area throat where the gas velocity is raised to 200 to 600 feet per second. Water spray is introduced into the throat from above. The water droplets contact and adhere to particulates increasing their mass. This caused the particles to move downward for collection in a gas liquid separator. Typical pressure drops across a Venturi scrubber range from 20 to 30 inches of water column and typical water consumption rates range from 5 to 10 gallons per 1000 cubic feet of stack gas.

E.4. FLUIDIZED BED

A typical fluidized bed incinerator is shown in Figure 5, and desribed in paragraph H.1. of the facility planning section.

E.4.a. Operating Schedule

Because of the heat reservoir afforded by the sandbed, fluidized bed incinerators are well suited to intermittent or batch operations. While the equipment required for 8-hour, 5-day operations is three to four times that for continuous operation, the fuel required to maintain the incinerator near operating temperatures overnight is minimal.

E.4.b. Reactor Design

Fluidized bed reactor loading rates for sewage sludge are typically in the range of 10 to 20 lbs/hr/sf on a dry solids basis with 12.7 lbs/hr/sf being the average for eleven installations by one manufacturer (68). The bed area and diameter are determined from the sludge flow and the loading rate. Figure 15 is a plot of sludge loading rates vs. bed area for the installations of one manufacturer of fluidized bed furnaces. Table 16 is a tabulation of typical loading rates on a wet sludge basis.

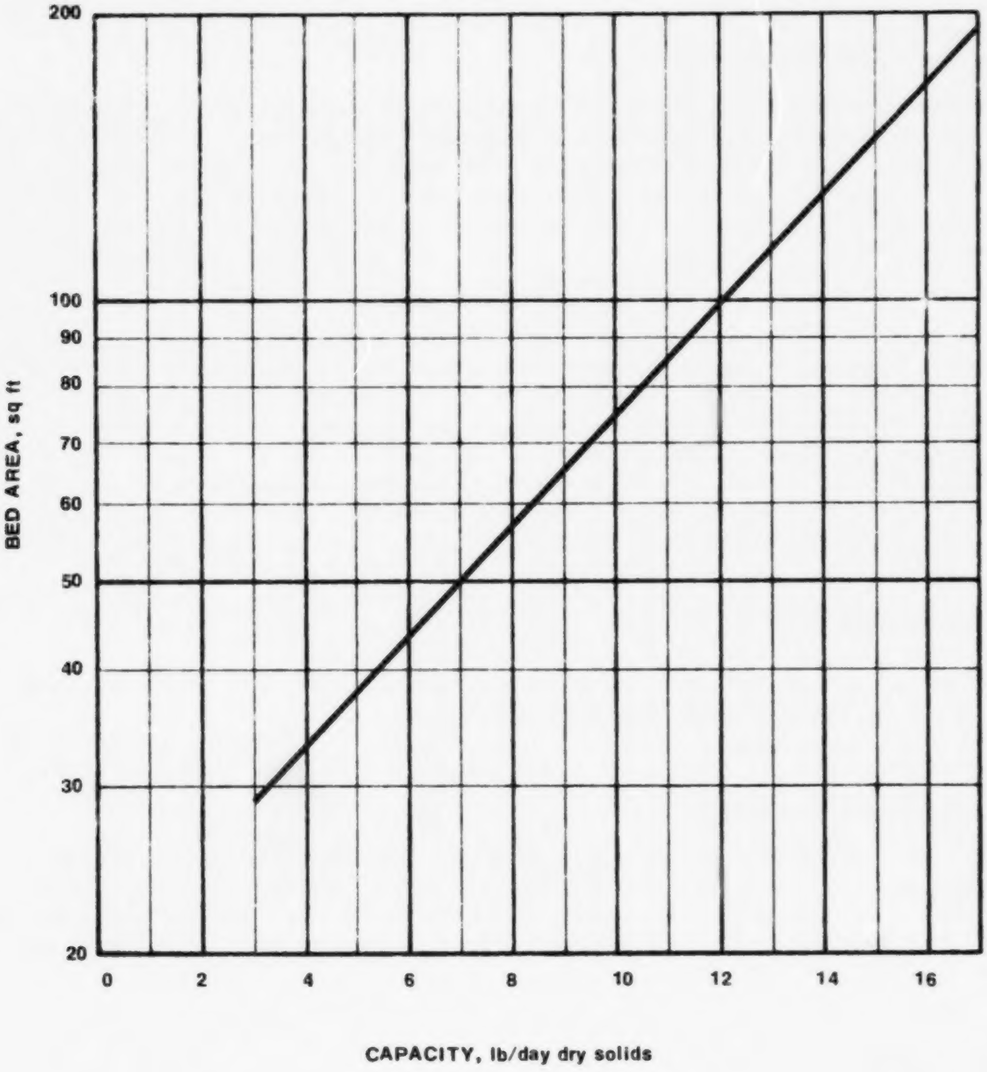


Figure 15. Fluidized bed, bed area vs. capacity.
(From data in reference 68)

TABLE 16. FLUIDIZED BED FURNACE LOADING RATES

Type of sludge	Solids, %	Vol. solids, %	Chemical concentration,* mg/l	Wet sludge loading rate, lb/sq ft/hr
Primary	30	60	N/A	14
Primary + $FeCl_3$	16	47	20	6.8
Primary + low lime	35	45	298	18
Primary + WAS	16	69	N/A	6.8
Primary + WAS + $FeCl_3$	20	54	20	8.4
Primary + $FeCl_3$ + WAS	16	53	20	6.8
WAS	16	80	N/A	6.8
WAS + $FeCl_3$	16	50	20	6.8
Digested primary	30	43	N/A	14

*Assumes no dewatering chemicals.

The required reactor volume, and thus its height, are determined by the burning rate and detention time needed for satisfactory combustion of gases. The exact reactor dimensions would then be determined by consulting a manufacturer's table of standard dimensions.

The sandbed acts as the heat transfer medium and also serves to hold organic particles until combustion is complete and to grind ash particles, preventing the formation of clinkers. Fluidizing air is the air flow required to maintain the sand in a fluid state without excess carry-over of sand in the exhaust gases. Fluidizing air also supplies the combustion air. Air supplied to the reactor increases heat losses. Preheating of fluidizing and combustion air can, however, minimize those losses.

The sludge feed system should be designed for uniform distribution of sludge over the top of the bed. Where the supply of air to the process must be limited the sludge feed system should be designed to minimize the entry of air.

E.4.c. Auxiliary Fuel System

The design of the auxiliary fuel system should take into account the rate of fuel consumption for start-up (and shut-down), continuous operation and standby operation.

E.4.d. Combustion and Excess Air Components

E.4.d.(1) Incineration - The exact combustion air requirement is determined from the theoretical oxygen demand (THOD) of the sludge and auxiliary fuel. Air is approximately 21 percent oxygen, so the actual air requirement would be (100/21)(THOD). Operating experience has shown that excess air is required for complete combustion, usually on the order of 20 to 60 percent of the theoretical requirement. Assuming 50 percent excess air, then, the actual air requirement would be (150/21)(THOD).

E.4.d.(2) Pyrolysis - Pyrolysis, as proposed for sewage sludge reactors, is starved air combustion, wherein a portion of the pyrolysis products are burned within the reactor as the heat source for the reaction. Air supply requirements will be less than the theoretical oxygen demand. The exact air supply requirement would be determined empirically for optimum performance. One possible design approach would be to size the air supply system for incineration and provide controls to permit cutting back the supply to the level required for pyrolysis.

E.4.e. Incineration Ash Systems

Ash handling and disposal systems should be sized for the maximum anticipated ash flow, or sufficient storage provided to permit lesser capacities. All fluidized bed incinerator ash is carried from the reactor in the exhaust gases and collected by the air pollution control equipment.

The details of ash handling systems for fluidized bed incineration are similar to those for multiple hearth incineration which are discussed in paragraphs E.3.e, E.3.e.(1) and E.3.e.(2).

E.4.f. Air Quality Control

After-burners are not generally required for fluidized bed reactors. Scrubbers of various types and electrostatic precipitators are used for particulate removal, with the electrostatic precipitator being more efficacious, but more capital intensive. The design of air quality control equipment should be based on the actual volume of gases expected to pass through the stack at the actual stack exhaust temperature. Equipment design should consider the corrosive nature of stack gases.

The design of the air pollution control system should take into account the fact that all the ash from the process will be carried from the reactor in the exhaust gases together with a quantity of fine sand particles from the incinerator bed.

E.5. WET AIR OXIDATION

The wet air oxidation process is described in Part 1, paragraph H.1.c.

Wet air oxidation is a proprietary process and should be designed with the close cooperation of the manufacturer. While no specific parameters are listed here, the following components of the system must be considered in the design.

- Sludge grinder
- Sludge storage
- Sludge pumping
- Air compressor
- Heat exchanger
- Steam generator
- Gas/liquid separator
- Auxiliary fuel system
- Air quality control
- Residue treatment
    - Dewatering
    - Handling
    - Disposal
    - Liquor treatment

E.6. OTHER PROCESSES

There are several other processes, most of them proprietary, which have been used or proposed for the combustion of sludge. While the discussions included herein do not cover the design of these processes, the basic elements of their design are similar to those for multiple hearth and fluidized bed reactors.

E.6.a. Cyclonic Reactors

Horizontal cyclonic reactors are described in paragraph H.1.a.(3) of the facility planning section.

E.6.b. Electric Incinerators

Electric Incinerators are described in paragraph H.1.a.(3) of the facility planning section.

E.6.c. Proprietary Pyrolysis

Proprietary pyrolysis processes are described in paragraph H.1.b. of the facility planning section.

E.7. CO-DISPOSAL

The co-combustion of sludge with solid waste generally takes one of two forms:

- Incineration or pyrolysis of sludge with the solid waste stream in a solid waste incinerator

- Use of shredded and classified solid waste as an auxiliary stream in a sludge incinerator

The co-disposal facility design should take into account the different handling equipment required for solid waste and wastewater sludge. For refuse derived fuel systems shredding and classification equipment should be included in the design. The use of unclassified solid waste could lead to a slag production as well as increased ash production.

E.8. AUXILIARY FUEL SELECTION

The term auxiliary fuel means the source of additional heat required, above the heat content of the sludge, to bring the incinerator to operating temperature, to begin sludge burning, to maintain sludge burning for non-autogenous sludges, to hold the incinerator at or near operating temperature during standby periods, and to control incinerator cooling rates during shut-down. The auxiliary fuels presently in use are:

- Gases natural gas, propane, liquified petroleum gas
- Fuel oils
- Powdered coal
- Refuse derived fuel
- Electricity

Electricity is used as an auxiliary fuel only in electric incinerators, and will not be discussed further.

The value of powdered coal and refuse derived fuel is strictly as a source of additional heat for burning of non-autogenous sludges, and either a gas or fuel oil system must be provided for the other auxiliary fuel functions. The use of coal or refuse as auxiliary fuel should not be overlooked, however, because of their potentially low cost per Btu. In addition, refuse and powdered coal may have value as sludge conditioners, improving the yield of dewatering processes.

Gases and fuel oils are the most common auxiliary fuels, being usable for all the auxiliary fuel requirements. If natural gas is elected as the auxiliary fuel source, it may be an interruptible service, in which case measures should be taken to protect the incinerator from damage from an uncontrolled shutdown. This will most often take the form of a gas, such as propane, stored on the site in at least sufficient quantity to control temperature changes during shut-down. Additional qualities may be provided for some fixed period of continuous operation. Backup sources of fuel may be advisable for other types of gas or oil supplies, depending on the circumstances.

E.9. RELIABILITY AND FLEXIBILITY

The combustion process must be designed with reliability, operating flexibility and future design flexibility in mind. Facilities must be designed in accordance with the EPA Technical bulletin Design Criteria for Mechanical, Electric, - and Fluid System and Component Reliability (58).

E.9.a. Expandable Facilities

When future increases in sludge production beyond the capacity of the equipment installed are anticipated by the facility plan, the process should be designed with expansion in mind. Provisions for future expansions may include space allocations for future equipment, blind flanges for future piping corrections and provisions for structural extensions.

E.9.b. Multiple Units

The provision of multiple process units can enhance a combustion system's reliability by making it less vulnerable to complete shut-down due to mechanical failure or routine maintenance.

E.9.c. Alternative Reduction and/or Disposal Methods

It may be necessary to provide an alternative means of disposing of sludge in the event of a failure of the combustion process. A common example is providing a means of loading unincinerated sludge into trucks for transportation to a landfill. The alternative disposal or combustion method should not be subject to common mode failures with the principal method.

E.9.d. Storage

Storage is often used to provide both reliability and operating flexibility for the sludge management system. Storage can permit scheduling of operations as desired, can permit the system to be out of service for a predetermined period of time, and can increase the effective capacity of the combustion system by smoothing the sludge and solids flow rate variations.

E.9.e. Standby Power

Standby power should be provided when required to prevent damage to equipment or to maintain operation. Examples of the former condition are multiple hearth furnace shaft cooling air fans, which should always be provided with a standby source of power.

E.9.f. Standby Fuel

Standby fuel supplies should be provided where required to prevent refractory damage or to maintain continuous operation.

E.10. MASS BALANCE

The calculation of the expected flow of mass into and out of the combustion process will aid in establishing its design parameters. The mass balance calculation must be performed in conjunction with the energy balance discussed later in this section. The mass of inputs to the combustion process must equal the mass of outputs. See Appendix C for sample calculation.

E.10.a. Inputs

See part H.2.a. in the facility planning section.

E.10.b. Outputs

See part H.2.b. of the facility planning section.

E.11. ENERGY BALANCE

The energy balance, together with the mass balance, provides the basic data for establishing the design parameters of the combustion process. The total input and output of the combustion process must be equal.

E.11.a. Inputs

See part H.3.a. of the facility planning section.

E.11.b. Outputs

See part H.3.b. of the facility planning section.

E.12. ENERGY RECOVERY SYSTEMS

If energy recovery is planned as a part of the combustion process, the energy recovery system design should be closely coordinated with the combustion system design. The design of energy recovery systems should take into account the degree of reliability of the energy source. It may be necessary to provide back-up energy sources for critical uses, such as digester heating. Where pyrolysis products are to be used as energy sources on or off-site conditioning systems may be required to make the product usable. Energy recovery systems will be of the following types:

- Multiple hearth furnace center shaft cooling air recycle
- Stack gas heat exchange
- Reactor water jacket
- Wet air oxidation effluent heat exchanger
- Pyrolysis product recovery

E.13. ENVIRONMENTAL IMPACTS

The design of the sludge combustion system should consider the impact on the environment, minimizing any deleterious effects. Air impacts are minimized by properly designed air pollution control equipment. Land, surface water, and groundwater impacts are a function of the ultimate disposal systems and are discussed under the appropriate sections. The social and health impacts are closely tied to the air impacts and are minimized by designing for minimum air pollution. The economic impact of the system design is related to the proper design of the reactor, selection of the auxiliary fuel, and design of the energy recovery systems.

Section F - SLUDGE FOR OFF-SITE USE BY OTHERS

Systems which process sludge for off-site use by others are of widely varying types. The principle processes which produced usable products are:

- Drying
    - Flash drying
    - Drying beds
    - Drying lagoons
- Composting
    - Windrow composting
    - Static pile composting
- Combustion
    - Incineration ash
    - Wet air oxidation residue
    - Pyrolysis process residues

Combustion processes are discussed in detail in the preceeding section and will not be discussed further herein, except to mention that many of the product safety and packaging design features discussed also apply to combustion process residues.

The processes discussed in this section are all intended to produce a sludge product which is useful as a soil conditioner or fertilizer.

F.1. SLUDGE CHARACTERISTICS

The characteristics of the sludge which have the greatest impact on the design of the sludge processing are moisture content and sludge flow. Nutrient (nitrogen, phosphorus, potassium) content will affect the values of the final product as a fertilizer while heavy metal, toxic organic compound and pathogen contents will affect its safety and the suitable markets.

F.1.a. Type of Processing at Treatment Plant

The degree of stabilization may be specified by local regulatory agencies to prevent potential health hazards. The degree of dewatering will determine the size and type of processing facilities.

F.1.b. Quantity: Maximum, Average, Minimum

The quantity of sludge produced will determine the size of the processing units, the amount of land required for lagoon, drying bed, and composting operations and the quantity of bulking agent required for composting operations. Sludge quantities must take into account chemicals added to the sludge in conditioning and dewatering steps.

F.1.c. Analysis

The solids content of the sludge will be an important factor in sizing drying processes, in determining bulking agent requirements for composting, and in assessing the sludge's value as a supplemental solids source for solid waste composting. Dewatered sludge moisture content of 20 percent are typical for sludge to be composted, while sludge flow to drying beds and lagoons is typically undewatered anaerobically digested sludge with a solids content of 2-6 percent. Sludges to be heat dryed should be dewatered to the highest cost-effective solids content, 20 percent being typical.

F.2. COMPOSTING

Composting processes are described in Part I.2.b. of the facility planning section. Typical design criteria for composting operations are summarized in Table 17.

F.2.a. Bulking Agents

The dewatered sludge (typically 20 percent) solids is delivered to the site and is usually mixed with a bulking agent. The purpose of the bulking agent is to increase the porosity of the sludge to assure aerobic conditions during composting. If the composting material is too dense or wet it may become anaerobic thus producing odors; or if it is too porous the temperature of the material will remain low. Low temperatures will delay the completion of composting and reduce the kill of pathogens.

TABLE 17. TYPICAL COMPOSTING DESIGN CRITERIA

Loading Rates	
Dewatered sludge	20 to 25 percent solids 1 dry ton solids is equal to approximately 7 cubic yards of dewatered sludge
Sludge - Bulking agent Mix ratio	2.5 to 3.0 parts bulking agent to 1 part dewatered sludge by volume
Bulking agent	Requires 17 to 21 cubic yard per dry ton of sludge.
Composting period	14 to 21 days
Curing period	30 days
Expected Performance	
Compost production	
Unscreened	26 cubic yard per dry ton sludge
Screened 1/2 inch screen)	7 to 9 cubic yard per dry ton sludge
Minimum composting temperature	55 to 60°C - Forced air static pile; 50 to 55°C - Windrow
Finished compost	
Moisture content	40 to 50 percent
Volatile solids	40 percent
Bulking agent recovery	Variable depending on type of agent, degree of screening, but in range of 60 to 80 percent following screening.

Sidestream (Runoff water)

Data are not available on runoff water characteristics except that the quantity may vary from 6 to 20 gallons per day per pile containing 50 cubic yards of sludge during dry weather.

Various bulking agents have been used and several typical agents are:

- Unscreened finished compost
- Shredded and classified solid waste
- Wood products wastes
    - Wood chips
    - Bark chips
- Other wastes
    - Rice hulls
    - Licorice roots
    - Peanut shells

Generally, one part sludge 20 percent solids is mixed with three parts bulking agent although this mixture can be varied depending on solids content of sludge, type of bulking agent, and local conditions.

F.2.b. Sludge Receiving and Mixing

The design of the sludge receiving and mixing area should include facilities for sludge storage, bulking agent storage, a mixing area, and sufficient maneuvering space for the mixing equipment. At very large plants mixing may be performed by a composting auger, but the majority of facilities will use a front end loader. Surface area requirements for sludge mixing piles are typically 30 to 60 square feet per cubic yard of sludge to be mixed. To this must be added the area required for sludge and bulking agent storage and equipment maneuvering. Mixing pile dimensions should be suited to the mixing equipment to be used. Concrete pads are typical.

F.2.c. Windrow

This method is described in Part I.2.b.(1) of the facility planning section. For composting periods of 14 to 21 days areas of 500 to 1500 sq ft wet basins, are required for each cubic yard per day wet sludge flow. Approximately 100 percent additional area is required for maneuvering of equipment. In locations that receive substantial rain, windrow areas should be paved to facilitate operation.

F.2.d. Static Pile

This process is described in Part I.2.b.(2) of the facility planning section. Static piles typically require areas of 8 sq ft/cu yd of mixture or 28 to 33 sq ft/cu yd of sludge. For composting periods of 14 to 21 days, area requirements are 390 to 690 sq ft/cu yd/day on a wet sludge flow basis. Approximately 100 percent additional area should be allowed for pile construction equipment maneuvering and aeration equipment. Composting areas should be paved to facilitate operation.

F.2.e. Mechanical Systems

Mechanical systems are described in Part I.2.b.(3) of the facility planning section.

Mechanical composting systems are proprietary and should be designed in close cooperation with the equipment manufacturers.

F.2.f. Curing

Following composting, the product is removed from the windrow or static pile and cured in storage piles for 30 days or longer. Curing may be performed before or after screening. Curing piles should be as large as possible to minimize space requirements. Heights of 10 feet and widths of 20 feet are the maximum dimensions practical with a typical front end loader. Large operations with more sophisticated equipment can build more space efficient curing piles. For 30 days curing pile areas of 170 sq ft/cu yd of curing compost are typical. Approximately 100 percent additional space should be allowed for equipment maneuvering. Screening of compost prior to curing can significantly reduce curing area requirements.

The curing area need not be paved for ease of handling, but should be accessible for movement of the product to the screening or packing stage.

F.2.g. Screening

Compost is typically screened with a horizontal rotary type screen with 1/4 to one inch openings. Vibratory screens have also been successful. Bulking agents retained by the screen is recycled to the mixing stage. Screening may be performed before or after curing.

F.2.h. Facilities

The bulking agent storage areas should be adjacent to the receiving and mixing area and should be accessible for new bulking agent deliveries and movement of recycled bulking agent from the screening area. Screening should not be conducted during heavy rainfall or high wind in an uncovered area. Consideration should be given to equipment parking, maintenance and fuel needs. Covered storage may be advantageous. Maintenance will usually be performed off-site. On-site fueling facilities should be provided for all but the smallest facilities. In addition to possible covered equipment storage, a small building with office space, and a locker room with showers should be provided. The building should also include a lunch room, which may be combined with the office space. Fencing around the entire site is advisable. Eight foot high chain link fences with three top strands of barbed wire are usually satisfactory, although the fencing may be reduced in areas where the potential for vandalism is low.

F.2.i. Equipment

Table 18 lists the equipment requirements for typical windrow and forced air static pile operations. Actual equipment requirements will vary widely with the equipment available, the size of the operation, and possible alternate uses of the equipment at other sites.

TABLE 18. COMPOSTING EQUIPMENT

Windrow	Forced air static pile
Specialized windrow turner	Rubber tired front loader, 4 cu yd
Dump truck (*)	Dump truck (*)
Rubber tired front loader, 4 cu yd	Aeration blower assemblies and pipe
Drum screen	Drum screen
	Composting machine (**)

* Requirement will depend on site and operation

** May be helpful for mixing on larger applications

F.3. DRYING

F.3.a. Drying Beds

Drying beds are generally used for dewatering of well digested sludges. Attempts to air dry raw sludge usually result in odor problems.

The drying of sludge on sand beds is accomplished by allowing water to drain from the sludge mass through a base of supporting sand to drainage piping and natural evaporation to the air. As the sludge dries, cracks develop in the surface allowing evaporation to occur from the lower layers which accelerates the drying process.

Drying beds are generally open to the weather but may be covered with ventilated green-house type of enclosures where it is necessary to dewater sludge in wet or cold climates.

Figure 16 is a cross-section of a typical sludge drying bed.

The required surface area for sludge drying beds is dependent on such climatic factors as air temperature, relative humidity, amount and rate of precipitation, percentage of sunshine, and wind velocity.

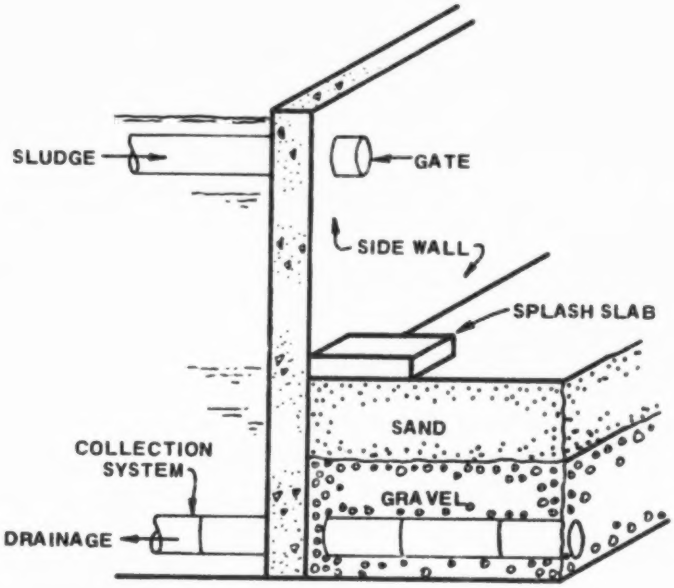

SLUDGE
GATE
SIDE WALL
SPLASH SLAB
SAND
COLLECTION SYSTEM
GRAVEL
DRAINAGE

Figure 16. Typical sludge drying bed construction.

Table 19 is useful in evaluating the adequacy of the total surface area. Sludge beds consist of perforated or open joint drainage pipe laid within a gravel base. The gravel is covered with a layer of sand. Partitions around and between the drying beds may be of concrete, wood or earthen embankment.

TABLE 19. DRYING BED LOADING RATES

Condition	Open beds	Covered beds
Primary digested sludge, sq ft/cap	1.0 - 1.6	0.75 - 1.0
Primary and humus digested sludge, sq ft/cap	1.25 - 1.75	1.0 - 1.25
Primary and activated digested sludge, sq ft/cap	1.75 - 2.5	1.25 - 1.5
Primary and chemically precipitated digested sludge, sq ft/cap	2.0 - 2.5	1.25 - 1.5
Solids loading rate, lb/yr/sq ft	up to 25	up to 40
Moisture content of dried sludge, percent	50 - 60	50 - 60

Table 20 is useful in evaluating sludge loading depth, base design, wall design and underdrain design.

Many design variations are used for sludge drying beds including the layout of the drainage piping, thickness and type of materials in the gravel and sand layers, and construction materials used for the partitions. The major variation is whether or not the beds are covered. Any covering structure must be well ventilated. In the past, some beds were constructed with flat concrete bottoms for drainage without pipes, but this construction has not been very satisfactory.

Consideration must be given to sludge removal. Hand removal by shoveling sludge into trucks is typical for small plants. Mechanical removal of sludge from drying beds has been practiced for many years at some large treatment plants, but now it is receiving more attention because of the need to minimize labor costs. Mechanical devices can remove sludges of 20 to 30 percent solids while cakes of 30 to 40 percent are generally required for hand removal. Small utility tractors with modified front end loaders are often used for removal.

TABLE 20. DRYING BED DESIGN PARAMETERS

Design parameter	Typical design values
Sludge depth, inches	8 - 12
Gravel layer depth, inches, typically 3-inch layers graded from coarse at bottom to fine at top	12 - 18
Sand layer depth, inches, typically 0.55 mm size	6 - 12
Drainage pipe spacing, feet typically 6-inch diameter	8 - 20
Typical module size, feet:	
Length	20 - 100
Width	20 - 25

Most removal systems, either hand or mechanical, benefit by the provision of concrete treadways in the drying bed for mechanical equipment or trucks. Beds can also be designed with flexible plastic drainage pipe to allow tractors with floatation tires directly on the beds.

In some instances drainage of the sludge can be speeded up or increased by adding chemicals. Where it is known that a sludge is relatively difficult to dewater by mechanical methods, it will most likely be difficult to dewater by sandbeds, drain poorly and dry slowly. Addition of conditioning chemical facilities should be provided in these cases.

F.4.b. Drying Lagoons

Sludge is periodically drawn from a digester, placed in the lagoon, removed after a period of drying, and the cycle repeated. Drying lagoons are not typically provided with an underdrain system as most of the drying is accomplished by decanting supernatant liquor and by evaporation. Plastic or rubber fabrics may be used as a bottom lining, or they may be natural earth basins. Supernatant liquor and rainwater drain off points can be provided, with the drained off liquid returned to the plant for further processing.

Table 21 presents some typical parameters for the design of drying lagoons.

TABLE 21. DRYING LAGOON DESIGN PARAMETERS (7)

Design parameter	Range of design values
Solids loading rate	2.2 - 2.4 lb/yr/cu ft of lagoon capacity
Area required:	
Examples:	
Dry climate, primary sludge	1 sq ft/capita
Wet climate, activated sludge	3-4 sq ft/capita
Dike height	2 ft
Sludge depth after decanting (depths of 2-4 ft have been used in very warm climates)	15 in
Drying time for depth of 15 in or less	3 - 5 months

The design of the drying lagoons must also include adequate provisions for decanting the lagoon and for removal of sludge. Methods for decanting the lagoons include overflow weirs, partially or completely along one end of the lagoons and stand pipes. For shallow lagoons sludge can be removed by front end loader and truck. Deep lagoons (>4' deep) may require a dragline or clamshell. Lagoons should be ramped for equipment access and, if permanent, berms should be designed to support the constant use of heavy equipment. Temporary berms can be rebuilt after every use.

F.3.c. Heat Drying

Flash dryers and rotary kilns are sized on the basis of the solids loading rate and heating requirements. The principles that apply are similar to those used in designing sludge incinerators. Flash dryers and rotary kilns are usually available in several module sizes with sludge drying capacities typically ranging from 40 pounds per hour to 2,400 pounds per hour of sludge feed. The expected performance from a flash dryer or rotary kiln is a dried sludge with a solids content ranging from 90 to 98 percent. Heat dryers are usually designed with the close cooperation of one or more manufacturer of drying equipment and specific design factors such as loading rates are functions of the equipment used. There are two basic types of heat dryers, flash dryers and rotary kilns.

F.3.c.(1) Flash Dryers - Before introduction into the flash dryer, the sludge must undergo thickening and dewatering. The incoming dewatered sludge is blended with a portion of the previously heat dried sludge in a mixer. (See Figure 9). Hot gases from the furnace at approximately 1,200° to 1,300°F (650° to 700°C) then are mixed with the blended sludge before drying in the cage mill. Agitation in the cage or jet mill dries the sludge to approximately 2 to 10 percent moisture and reduces the temperature to approximately 300°F (150°C) before cyclone separation of the solids from the gases. A portion of the dried solids are recycled to the mill and the rest are stored for use or incinerated. The gases from the cyclone separators are conveyed by the vapor fan to the deodorization preheater in the furnace where the temperature is raised to approximately 1,200°

to 1,400°F (650° to 760°C). The deodorized gases release a portion of the heat to the incoming gases and release more heat in the combustion air preheater. The temperature is reduced to approximately 500°F (260°C) before the gas is scrubbed for particulate removal and conveyed to the stack by the induced draft fan. If the dried solids are not used in the furnace as a fuel, then auxiliary fuel such as gas, oil, or coal is necessary.

The design of flash drying systems must take into account the following major subsystems:

- Flash drying cycle
  - Wet sludge conveyor
  - Sludge dry product mixer
  - Cage or jet mill
  - Cyclone
- Incineration cycle
  - Combustion air fan
  - Furnace
  - Combustion air preheater
- Effluent gas cycle
  - Deoderizing air preheater
  - Combustion air preheater
  - Dust collector
  - Induced draft fan
- Product handling cycle
  - Dry product conveying
  - Product storage
  - Product loading or packaging

Dust control must be given careful consideration in flash drying systems. The product is a light, finely divided, combustible, abrasive material which presents serious safety, maintenance, and housekeeping problems if not properly controlled. When mixed with air the dust can be highly explosive and when inhaled could aggravate respiratory problems. The dust is a major cause of mechanical equipment failures at existing plants due to its action on bearings and other moving parts. Adequate measures must be included in the project design to reduce airborne dust to a minimum and to prevent conditions conducive to explosions.

F.3.c.(2) Rotary Kiln Dryers - Rotary kiln dryers are described in Part I.2.a.(3)(b) of the facility planning section.

The design should consider the following major components of the system:

- Rotary kiln
- Sludge feed system
- Effluent gas system
- Product handling system

While dust is not as severe a problem as with flash dryers, its control must be considered in the project design.

F.3.c.(3) Air Pollution Control - Heat drying in general, produces an exhaust that contains unacceptable quantities of air pollutants. Therefore, the system design usually includes equipment necessary to reduce the emissions to acceptable levels. This may require particulate collection efficiencies as high as 96 to 97 percent. Air pollution control requirements for heat drying are very similar to those for sludge incineration and the reduction section of this manual shall be consulted. In addition to cyclonic and wet scrubber and electrostatic precipitators, dust filters are sometimes used for heat drying systems.

F.3.c.(4) Auxiliary Fuel - Substantial quantities of auxiliary fuel are required for heat drying systems. The fuels most often used are:

- Gas
- Oil
- Coal
- Dried sludge

Gas, oil, and coal are used for cage mill flash dryers. Dried sludge is also sometimes used, but an additional supply of gas or oil must be provided for system startup and sludge ignition in that event. Gas and oil are suitable fuels for both jet mill flash dryers and rotary kilns.

F.4. COMPOSTING WITH REFUSE

Co-composting of sludge with refuse generally falls into one of two categories:

- Use of refuse as a bulking agent in sludge composting
- Use of sludge as a nutrient and moisture source in solid waste composting

The design of co-composting systems must take into account the differing requirements for sludge and solid waste composting.

F.4.a. Refuse As a Bulking Agent

Sewage sludge has too high a moisture content for successful windrow or static pile construction without the aid of a bulking agent. The cellulose (paper and some garbage) fraction of solid waste may offer a suitable and economical bulking agent. Design of systems for using refuse as a bulking agent should include adequate shredding and classifying facilities. If the product is to be screened with a finer screen that the typical shredded refuse partical size, classification facilities may be unnecessary.

F.4.b. Sludge As a Nutrient Source

Solid waste generally requires supplemental nitrogen and moisture for successful composting. Sewage sludge has been suggested as an economical source of the additional nitrogen (54). Composting facilities to use sludge for supplemental nitrogen should provide facilities for distributing sludge and mixing it with the solid waste. It should be recognized that sludge generally has a higher pathogen content than solid waste, and great care must be taken in its handling.

F.5. NUTRIENT ENRICHMENT

It may prove cost-effective to increase the market value of the sludge product by nutrient enrichment. While nitrogen and phosphorus (phosphoric acid) contents can be increased with a subsequent increase in value, the greatest nutrient shortcoming of most sewage sludge products is the potassium (potash) content. Nutrient enrichment processes may be part of the sludge management system or they may be practiced by fertilizer processors who purchase the unenriched product from the wastewater agency.

Nutrient enrichment is a fertilizer manufacturing process and the design of nutrient enrichment facilities should involve the close cooperation of a producer or producers of fertilizer manufacturing equipment.

F.6. PACKAGING

The project design must provide facilities for some combination of product packaging, loading, and transportation. The design of these systems will depend heavily on the end use of the product.

F.6.a. Pick-up By User

By far the most common system of delivering sludge for off-site use by others is to allow or encourage individuals to pick up lagoon or bed dried sludge at the treatment plant. In this event, provisions should be made to avoid disrupting other plant operations. Sludge may be loaded by the user or by utility personnel. If it is planned for the user to remove dried sludge directly from drying beds, provisions should be included in the design to prevent damage to sand layers and underdrain systems caused by untrained personnel removing sludge from bed. The same concept is sometimes applied to larger deliveries, with user owned trucks loaded with sludge during regularly scheduled drying bed or lagoon cleanings.

F.6.b. Bulk Delivery to User

Sludge products are often delivered in bulk to the users. Trucks, railroads and barges have been used. The section on sludge transport has more information on the design of sludge transportation facilities.

F.6.c. Bagged

Bagging facilities should be designed in close cooperation with manufacturers of suitable bagging equipment. If the bagged product is to be sold on-site a separate covered storage and marketing area should be provided and located so as to avoid interference with other plant operations.

If the bagged product is to be sold off-site suitable loading and transportation facilities must be provided.

F.6.d. Instructions and Guidelines for Use

Each bulk pick-up or delivery and each bag of sludge should be accompanied by detailed instructions and guidelines for use, explaining the following:

- The exact nature of the material
- The guaranteed nutrient analysis
- Any limitation on its use, such as application to food chain crops
- Other suggestions and pointers on its use

In the case of bagged product, it is usually convenient to print the suggestions and guidelines directly on the bag.

F.6.e. Brand Name

The selected brand name should be prominently displayed on bags and instruction sheets, and in other appropriate ways.

F.7. ENVIRONMENTAL IMPACTS

The design of the sludge processing system should minimize any deleterious environmental impacts.

The only system considered which has a significant impact on air quality is heat drying. Air impacts, especially airborne dust can be minimized by adequately designed emission control equipment and by including dust control measures in the project design. The impacts of the system on the land are a function of the product quality. Impacts are both positive, improved moisture holding characteristics and nutrient levels, and negative, heavy metals, toxic organics, an pathogens. In most cases, the wide dispersion of the sludge product will minimize deleterious effects. Adequate warning should accompany any product, indicating recommendations for restricted use when distributed to the public. Runoff from drying beds, drying lagoons, and composting operations can affect surface water quality if not collected and treated. Provisions should be made in the project design for collecting and treating the runoff. In most cases this will be by returning the runoff to the wastewater treatment process, although separate treatment facilities may sometimes be more cost-effective. Surface water impacts due to product use will generally be minimal due to the wide dispersion of the product. Groundwater impacts of sludge processing systems are due to infiltration composting operations. Groundwater impacts from product use are generally minimal, but may be significant in exceptional cases. Infiltration and percolation can be minimized by proper design of sludge lagoons, including impermeable liners when necessary.

Social impacts of all sludge processing systems include odors and noise. Odors are a particular problem with lagoons and drying beds and are best minimized by only drying well stabilized sludges. Composting operations present potential odor and noise problems. Odors can be reduced by proper composting procedures. In static pile composting the provision of a small deodorizing pile of finished compost on the blower discharge has been found helpful. Heat drying systems may require deodorizing burners or heaters to control odors from volatile hydrocarbons vaporizing in the process.

The safety of the product is a primary concern in sludge processing systems. While little can be done within the processing system to control heavy metals and toxic organics contents, the system must provide adequate pathogen reduction for the end use. Lagoon and drying bed sludges may require disinfection. Properly operated composting and heat drying operations will generally provide adequate pathogen reduction. Control of disease vectors, such as flys, mosquitos, and rodents, must be given adequate consideration. Flys are a problem with all sludge processing systems, but particularly with sludge drying beds.

Mosquitoes are best controlled by design of the site grading so that potential breeding spots, such as standing pools of water, are eliminated.

PART III

OPERATION AND MAINTENANCE MANUAL

OPERATIONS AND MAINTENANCE MANUAL

INTRODUCTION

The operation and maintenance manual is the key to a successful sludge management system. An inadequate manual can doom the best planned and designed system to failure, while a good manual can enable the plant personnel to operate and maintain the plant at an optimum effectiveness level. The operation and maintenance manual should be prepared in accordance with Considerations for Preparation of Operation and Maintenance Manuals (70). The design concepts should be clearly explained and procedures for operating and maintaining the facilities must be delineated. The manual is intended to be a guide for the operators of the treatment facilities and will help to ensure that they understand the key design features and the objectives for which the system was designed. The manual should include maintenance schedules, monitoring programs, and recommendations for manpower utilization. Additionally, potential problem areas, symptoms of process malfunction, and methods of control of adverse impacts should be described. Special considerations, such as agricultural practices for land application systems, should also be included.

The format of this checklist has been selected to enable the reviewer to enter a checkmark or comment to the right of each item. There are 5 major categories:

A. Sludge Transport
B. Land Application
C. Landfill
D. Combustion
E. Sludge Products for Off-Site Use by Others

Within each category are numerous sub-elements. Consideration of one or two of the major categories may be required for a particular review.

It is not necessary to include all the sub-elements. Only those concerned with the operation and maintenance of the selected sludge management system should be considered.

OPERATION AND MAINTENANCE MANUAL

CHECKLIST

A. SLUDGE TRANSPORT
  1. PIPELINE
  2. TRUCK
    a. Description of Equipment
    (Number and type of trucks, capacity of trucks.)
    b. Description of Facilities
    (Loading, unloading, washdown, fueling, and maintenance)
    c. Normal Operation
    (Operating schedule: Loading, time, travel time, unloading time, return time, fueling and daily maintenance time; route: normal and alternate; loading and unloading procedures)
    d. Emergency Procedures
    (Vehicle breakdown, sludge spill)
    e. Vehicle Safety Rules
    f. Impact Control
    (Environmental: air pollution, health disease vector control; Social: Noise, odor, traffic.)
    g. Personnel
  3. BARGE
    a. Description of Equipment
    (Number and type of barges, capacity of barges.)
    b. Description of Towing Arrangements
    (Tow contractor, operating hours, haul distance and route, barges per tow.)
    c. Description of Facilities
    (Loading, unloading, washdown and maintenance.)
    d. Normal operation
    (Operating schedule: loading time, travel time, unloading time, return time; route: loading procedures, unloading procedures.)
    e. Emergency Procedures
    (Tow vessel breakdown, sludge spill.)
    f. Safety
    g. Impact Control
    (Environmental: air pollution, surface water pollution; health: disease vector control; social: noise, odor.)
    h. Personnel
  4. RAILROAD
    a. Description of Equipment
    (Number and type of cars, capacity, ownership)
    b. Description of Facilities
    (Loading, unloading, washdown and maintenance.)
    c. Description of Haul Contract
    (Pick-up and set-out points and times)

d. Normal Operation ________
(Operating schedule: loading time, haul time, unloading time, return time; loading procedures, unloading procedures, pick-up and set-out procedures, moving cars on-site.)
e. Safety ________
f. Impact Control ________
(Environmental: air pollution; health: disease vector control; social: noise, odor.)
g. Personnel ________

B. LAND APPLICATION
1. PERMITS AND STANDARDS
a. Solid Waste Disposal ________
(Permit number, renewal date, if applicable, permit requirements, permit application guidelines, applicable Federal/State laws and agency regulations.)
b. Discharge Permits for Runoff and Leachate ________
(Permit number, renewal date, if applicable, permit requirements, permit application guidelines, Federal/State laws and agency regulations.)
c. Crop marketing ________
2. APPLICATION EQUIPMENT
a. Description of Equipment ________
(Number and type of application vehicles and capacities.)
b. Description of Facilities ________
(Washdown, fueling, maintenance, records and administration.)
c. Startup Procedures ________
(Equipment check, application schedule for the day.)
d. Normal Operation ________
(Field pattern, log sheet, applicator speed.)
e. Shutdown ________
(Equipment cleanup, completion and filing of log.)
f. Emergency Procedures ________
(Vehicle breakdown, sludge spills, injector clogging.)
g. Safety - Vehicle Safety Rules ________
h. Impact Control ________
(Environmental: soil pH, etc.; health: disease vectors; social: odor, noise)
i. Personnel ________
(Number, qualifications or training required)
3. FARM MANAGEMENT
a. Description of Equipment ________
(Tillage equipment, harvest equipment, other equipment.)
b. Description of Facilities ________
(Maintenance shops, crop storage, seed storage.)
c. Crop Management ________
(Crops grown, rotation schedule, consultants used, custom harvesting contracts.)
d. Contingency Procedures ________
(Equipment breakdown, crop problem identification [e.g. disease].)

e. Emergency Procedures
(Unacceptable increase in heavy metals or a toxic element, extreme or unusual weather conditions)
f. Personnel
(Number, qualifications.)

4. MONITORING
a. Parameters to be Measured
b. Procedures
c. How to Use Results
d. Reporting Procedures

C. LANDFILL

1. PERMITS AND STANDARDS
a. Solid Waste Disposal
(Permit number, renewal date, if applicable, permit requirements, permit application guidelines, Federal/State laws and agency regulations pertaining to sanitary landfills.)
b. Discharge Permits For Runoff and Leachate
(Permit number, renewal date, if applicable, permit requirements, permit application guidelines, Federal/State laws and agency regulations.)
c. Reporting Procedure for Spills of Raw or Inadequately Treated Wastewater
(Federal/State laws and/or agency regulations requiring reporting of bypass/spill conditions; owner's responsibilities, penalties; reporting procedure including telephone numbers and sample report format.)
d. Water Quality Standards
(Runoff receiving stream, adjacent streams where there is a potential of a spill, state stream classification system.)

2. DESCRIPTION OF LANDFILL
a. Definition of Sanitary Landfill
b. Design Criteria
(Trench fill or berm dimensions, cover dimensions, site life.)
c. Description of Site
d. Generalized Description of Operations

3. RELATIONSHIP TO OTHER UNIT PROCESSES
a. Pretreatment Processes
b. Sludge Transport
c. Runoff and Leachate Treatment
d. Co-disposal With Refuse

4. MAJOR COMPONENTS
a. Facilities
(Leachate control, gas control, runoff control, roads, soil stockpiles, inclement weather areas, structures, utilities, washracks, monitoring wells, equipment fueling and maintenance.)
b. Equipment
(Excavating, sludge handling, backfilling, mixing, compacting, grading, road construction.)

5. MONITORING
   a. Parameters to be Measured ________
      (Sludge, leachate, runoff, gas.)
   b. Procedures ________
   c. How To Use Results ________
   d. Reporting Procedures ________
      (Regulatory agencies, sample record and reporting forms.)
6. STARTUP PROCEDURES ________
   (Monitoring background conditions, initial trench, fill, or berm location, initial trench dimension, soil stockpile locations, liners, if any.)
7. NORMAL OPERATION
   a. Trench, Fill or Berm Locations ________
   b. Trench, Fill or Berm Dimensions ________
   c. Handling of Soil Removed From Trench ________
   d. Imported Soil ________
   e. Co-disposal Procedures ________
   f. Liners ________
8. EMERGENCY OPERATION AND FAIL-SAFE FEATURES
   a. Inclement Weather Operations ________
      (All weather roads, minimum on-site haul distance.)
   b. Gas Control ________
      (Permeable methods, impermeable methods, monitoring.)
9. LANDFILL COMPLETION
   a. Ultimate Use ________
   b. Grading at Completion of Filling ________
   c. Final Grading ________
   d. Landscaping ________
   e. Continued Leachate and Gas Control ________
10. SAFETY
    a. Soil Stability ________
    b. Equipment Operation ________
    c. Gas Control ________
11. IMPACT CONTROL ________
    (Environmental: Leachate, runoff; health: vectors, gas control, attractive nuisance; social: odors, noise.)
12. PERSONNEL ________

D. COMBUSTION
   1. PERMITS AND STANDARDS - AIR DISCHARGE PERMITS AND PERMIT REQUIREMENTS ________
      (Permit number, renewal date, if applicable, permit requirements, permit application guidelines, Federal/State/Local laws or agency regulations dealing with incinerator discharge permits.)
   2. DESCRIPTION OF FACILITY
      a. Design Criteria ________
         (Sludge loading rate, sludge characteristics, air pollution criteria, energy recovery.)
      b. Process Description ________

3. RELATIONSHIP TO OTHER UNIT PROCESSES
   (Pre-treatment process, sidestream treatment, ash disposal, co-disposal with refuse.)
4. MAJOR COMPONENTS
   a. Sludge Charging
   b. Reactor
   c. Auxiliary fuel
   d. Air Supply
   e. Steam Supply
   f. Energy Recovery
   g. Air Pollution Control
   h. Ash Handling
5. MONITORING
   a. Parameters
      (Sludge, stack emissions, temperatures, air flows, fuel consumption.)
   b. Procedures
   c. Using Results
   d. Reporting Procedures
      (Regulatory agencies, sample record and reporting forms.)
6. STARTUP
7. NORMAL OPERATION
8. EMERGENCY OPERATION AND FAILSAFE FEATURES
   (Unit process downtime procedures, flame safety system.)
9. SHUTDOWN
10. SAFETY
    (Flame safety system, auxiliary fuel safety, reactor safety.)
11. IMPACT CONTROLS
    (Environmental: air; social: odors.)
12. PERSONNEL

E. PROCESS FOR OFF-SITE USE BY OTHERS
   1. PERMITS AND STANDARDS
      (Air discharge permits and permit requirements, Federal/State/Local requirements for sale of fertilizers.)
   2. DESCRIPTION OF FACILITY
      a. Design Criteria
         (Sludge loading rate, sludge characteristics, bulking agents, product production rate, product quality.)
      b. Process Description
   3. RELATIONSHIP TO OTHER UNIT PROCESSES
      (Pretreatment processes, sludge transport, sidestream control and treatment, ash disposal, co-disposal with refuse.)
   4. MAJOR COMPONENTS
      a. Mixing
      b. Aerating
      c. Handling
      d. Screening
      e. Drying Beds or Lagoons
      f. Ash Disposal
      g. Auxiliary Fuel
      h. Air Supply

    i. Air Pollution Control ______
    j. Nutrient Enrichment ______
5. MONITORING
    a. Parameters ______
        (Sludge, product, stack emissions, temperatures, oxygen air flows, fuel consumption.)
    b. Procedures ______
    c. How to Use Results ______
    d. Reporting Procedures ______
        (Regulatory agencies, sample record and reporting forms.)
6. STARTUP ______
7. NORMAL OPERATION ______
8. EMERGENCY OPERATION ______
9. SHUTDOWN ______
10. SAFETY ______
    (Flame safety system, auxiliary fuel system, equipment operation safety, dust control.)
11. IMPACT CONTROL ______
    (Environmental: air, runoff; health: finished product, disease vectors; social: odors, noise, dust.)
12. PERSONNEL ______

OPERATION AND MAINTENANCE MANUAL

SUPPORTING COMMENTARY

The EPA publication Considerations for Preparation of Operation and Maintenance Manuals (70), referred to as Considerations in this publication, includes a detailed checklist and accompanying text describing the information to be included in a comprehensive operation and maintenance manual.

Considerations and the information included herein are intended to be flexible guidelines for the operation and maintenance manual evaluator and author and must be tailored for the individual facility. It may be desireable, for example, to prepare a separate manual for the sludge disposal site if it is remote from the wastewater treatment facility. In that case, the chapter on wastewater treatment facilities could be eliminated.

Section A - SLUDGE TRANSPORT

Manuals for sludge transport systems can generally follow the format listed in Considerations for pumping stations and pipelines, with modifications to suit the sludge transport system used.

The following discussion highlights the factors which are pertinent to the efficient operation and proper maintenance of sludge transport. It is by no means intended to be all-inclusive or to deal with every topic in great detail.

A.1. PIPELINE

The format and requirements for manuals for pumping stations and pipelines are described in great detail in Considerations and will not be repeated herein.

A.2. TRUCK

Truck transport equipment and facilities will require regular maintenance checks. A schedule of routine maintenance should be followed to insure trouble-free operation of the transport trucks and avoid untimely emergencies.

A.2.a. Description of Equipment

A full description of the type and number of trucks should be available to the drivers and other plant personnel. Maintenance manuals must be readily accessible so that routine and emergency repairs can be made quickly and correctly. Proper operation of the truck transport system depends on maximum utilization of the trucks without exceeding safe-load capacities.

A.2.b. Description of Facilities

A complete description of all transfer facilities should be available to the operating staff. Procedures for loading and unloading sludge should be clearly described and the staff given instruction on the function and proper operation of all components. A maintenance schedule should be established and followed to insure efficient operation and maximum performance of the equipment.

A.2.c. Normal Operation

Records of normal operation should be kept and periodically reviewed as a check of the efficiency of operations. The operating schedule and time spent performing each function (loading, unloading, haul, etc.) should be monitored. It can provide useful information for improving current operations and planning future changes. A map of the normal route and alternate routes should be available at all times. The drivers (regular and substitute) should be familiar with the various routes between the treatment plant and disposal site.

The operating staff must be familiar with the procedures for safe handling of the sludge. These should be as simple as possible so the operation is efficient and the potential for accidents is minimized.

A.2.d. Emergency Procedures

Emergencies are inevitable in this type of operation; however, their effects can be minimized if the operators are trained and prepared for them. Procedures for dealing with various types of emergencies, both general and specific, should be clear, concise and readily available.

Perhaps the two most obvious emergencies would be vehicle breakdown and sludge spills. The former will be minimized with regular maintenance. However, an adequate supply of spare parts, particularly those which commonly fail or are difficult to replace, should be stored at the treatment plant. A maintenance/repair manual should contain all the information necessary for repairing disabled transport vehicles. Sludge spills at the plant site can be avoided to some degree if the transfer equipment is easy to operate and the staff properly trained. Spills resulting from accidents involving the transport vehicle can result in unsafe road conditions and present a threat to public health. These should be cleaned up as quickly and thoroughly as possible to minimize the inconvenience they cause.

The manual should outline spill notification procedures identifying the agencies to be notified, such as the state health, highway and pollution control agencies, give the telephone numbers for such notification, and include copies of the reporting forms for the subsequent written report of the spill.

A.2.e. Vehicle Safety Rules

Only qualified personnel or supervised trainees should be operating the transfer and transport equipment. Safety rules should be posted and all drivers aware of highway rules and other considerations which will make their jobs safer.

A.2.f. Impact Control

Although mitigating measures to reduce adverse environmental impacts are considered during design, impact control should be practiced on a day-to-day basis. Air pollution equipment on the transport vehicles should be functioning properly. The exposure of the operation and general public to sludge should be minimized. Transport activities should be carried out with the least amount of disruption to public activities; this involves minimizing noise, odor and traffic congestion.

A.2.g. Personnel

Plant personnel should be adequate in number and experience to operate the transport facilities efficiently. They should be specially trained for the functions they perform, familiar with the duties of other operators, and prepared to handle any emergencies which may arise.

A.3. BARGE

As with truck transport, barging facilities require regular maintenance. The following discussion describes the general requirements for operating an efficient barging system.

A.3.a. Description of Equipment

All barging equipment should be fully described. The number, type and capacity of the barges are important information for the operators to have.

A.3.b. Description of Towing Arrangements

The towing arrangements should be clearly spelled out for the operating staff. The tow contractor, operating hours and phone number should be clearly posted in an obvious location. The route, haul distance and travel time should be recorded so that present operations can be monitored and future activities planned. A record of the number of barges towed per trip and the amount of sludge transported should also be kept.

A.3.c. Description of Facilities

A complete description of all transfer facilities should be available to the operating staff. Procedures for loading and unloading sludge should be clearly described and the staff given instruction on the function and proper operation of all components. A maintenance schedule should be established and followed to ensure efficient operation and maximum performance of the equipment.

A.3.d. Normal Operation

Records of normal operation should be kept and periodically reviewed as a check of the efficiency of operations. The operating schedule and time spent performing each function (loading, unloading, etc.) should be monitored. It can provide useful information for improving current operations and planning future changes. A map of the barge route should be available for tracking and emergencies.

The operating staff must be familiar with the procedures for safe handling of the sludge. These should be as simple as possible so the operation is efficient and the potential for accidents is minimized.

A.3.e. Emergency Procedures

Emergencies are inevitable with this type of operation, however, their effects can be minimized if the operators are trained and prepared for them. Procedures for dealing with various types of emergencies, both general and specific, should be clear, concise and readily available.

Perhaps the two most obvious emergencies would be the towing vessel breaking down and accidental sludge spills. The former is the responsibility of the towing company unless self-propelled barges are used, in which case regular maintenance practices will minimize equipment failures. Sludge spills at the plant site can be avoided to some degree if the transfer equipment is easy to operate and the staff properly trained. Spills resulting from accidents during transport can result in serious water pollution and associated health problems. Sludge should be contained as well as possible and transferred to another barge as quickly as possible to reduce risks.

The manual should outline spill notification procedures, identifying the agencies to be notified, such as the state health and pollution control agencies, give the telephone numbers for each notification and include copies of the reporting forms for the subsequent written report of the spill.

A.3.f. Safety

Only qualified personnel or supervised trainees should be operating the transfer and transport equipment. Safety rules should be posted and strictly enforced.

A.3.g. Impact Control

Although mitigating measures to reduce adverse environmental impacts are considered during design, impact control should be practiced on a day-to-day basis.

Air pollution equipment on the towing vessels should be functioning properly and measures must be taken to avoid surface water pollution. The exposure of the operators and the general public to sludge should be minimized. Transport activities should be carried out with the least amount of disruption to public activities; this involves minimizing noise, odor and other nuisances associated with the barging activities.

A.3.h. Personnel

Plant personnel should be adequate in number and experience to operate the transfer facilities efficiently. They should be specially trained for the functions they perform, familiar with the duties of other operators and prepared to handle any emergencies which may arise.

A.4. RAILROAD

Railroad transport of sludge is not common; however, it can be economically competitive with other methods (16.) The following sections briefly describe general considerations for operating rail transport facilities.

A.4.a. Description of Equipment

The railroad cars, whether leased or purchased, should be described in detail. The description should include the number and type, the capacity and ownership status of all cars. Operation and maintenance procedures should be described and available for use by the plant operators.

A.4.b. Description of Facilities

Sludge transfer facilities should be described in detail along with operating procedures for loading, unloading and general maintenance.

A.4.c. Description of Haul Contract

The details of the transport arrangement pertinent to the efficient operation of the system should be readily available to the plant operators. The pick-up and delivery schedule of the railroad should be posted and any modifications to the regular schedule clearly noted.

A.4.d. Normal Operation

A complete, detailed description of normal operations should be available to the plant operators. Records of the time required for various functions should be kept for historical purposes and to provide information for estimating future operations. All procedures for loading and unloading the cars and moving them about at the plant site should be outlined and reviewed periodically by the plant staff.

A.4.e. Safety

Only qualified personnel or supervised trainees should be operating the transfer or transport equipment. Safety rules should be posted and strictly enforced.

A.4.f. Impact Control

Although mitigating measures to reduce adverse environmental impacts are considered during design, impact control should be practiced on a day-to-day basis. Air pollution controls are the responsibility of the railroad. The exposure of the operators and the general public to sludge should be minimized. Transport activities should be carried out with the least amount of disruption to public activities; this involves minimizing noise, odor and other nuisances associated with rail transport.

A.4.g. Personnel

Plant personnel should be adequate in number and experience to operate the transfer facilities efficiently. They should be specially trained for the functions they perform, familiar with the duties of other operators and prepared to handle any emergencies which may arise.

Section B - LAND APPLICATION

The land application system should be operated and maintained in such a way that sludge is applied to the land without creating a nuisance or causing environmental degradation. Accurate record keeping is essential to safe operation. The operation and maintenance manual should be written with these concerns in mind. Loading rate determination is presented in Appendix A.

B.1 PERMITS AND STANDARDS

Numerous permits are required to operate a land application system. As well, certain standards must be upheld and reporting procedures for non-compliance clearly specified. Land application systems are often considered solid waste disposal systems from a regulatory agency viewpoint.

B.1.a Solid Waste Disposal

The information pertinent to operating the system which is specified in the solids waste disposal permit should be readily available. The operators should be familiar with specific information such as the issuing agency, permit number, renewal date and specific requirements. In addition, they should be aware of more general information such as permit application guidelines and laws and regulations pertaining to land application systems.

B.1.b. Discharge Permits for Runoff and Leachate

Permits will be required for the discharge of all uncontained and treated runoff and leachate. The operators should be familiar with the permit, including such information as the number, renewal date and specific requirements contained in it. Copies of all permits should be readily available for reference. Information such as application guidelines and general requirements should be available to operators.

B.1.c. Crop Marketing

Regulations concerning crop marketing or future crop production on the site must be followed. There may be restrictions on the ultimate use of crops grown on sludge-amended soils.

B.2. APPLICATION EQUIPMENT

Application equipment for injection of sludge can be attached to the back of a tank truck or pulled by a farm tractor usually, the track-laying type. Surface spreading can be accomplished by trucks or conventional farm manure spreading equipment.If the sludge is in liquid form, spraying may be accomplished by large nozzle sprinkler.

B.2.a. Description of Equipment

The O&M manual should contain a complete description of the equipment including number, type, and capacities of all application vehicles.

B.2.b. Description of Facilities

The site facilities or those related to application will usually consist of wash-down, fueling and maintenance facilities and an office or area for records keeping and administration. These facilities along with equipment within them should be described in the O&M manual.

B.2.c. Startup Procedures

Startup procedures can be divided into those required for daily or intermittent startup and those required for seasonal startup. Daily procedures include lubrication and liquid level checks as well as usual checks on all equipment. The seasonal checks consist mainly of preventive maintenance and cleaning. The daily startup includes provision of a drawing or map telling the operator which areas are to be covered and what quantities are to be applied.

B.2.d. Normal Operation

Normal operation procedures should be very specific with step-by-step instructions included. The operating instructions should include a field pattern for the application plan. This should show the areas to be covered and the order of application. At the end of the day the operator should file a log sheet showing areas and quantities applied. A sample log sheet should be included in the O&M manual. The O&M manual should provide a nomograph or tables to correlate applicator speed with amount applied (wet tons/acre). This correlation is specific to the type of sludge and equipment used.

B.2.e. Shutdown

Specific procedures need to be provided to insure equipment readiness for the following day. Injectors should be flushed with water to remove residual solids. These instructions should be included in the manual. The O&M manual should provide instructions on completion and filing of the log sheet mentioned previously.

B.2.f. Emergency Procedures

Emergency procedures should be provided with the O&M manual. They should include the following items. The manual should provide instructions concerning what action to take when a vehicle breaks down. This should include options for removing sludge before it goes septic. Cleanup, containment and reporting instructions for sludge spills should be included in the manual. Injector clogging can be caused by a minor obstruction or by faulty or damaged equipment. A troubleshooting table should be provided on how to correct this problem.

B.2.g. Safety - Vehicle Safety Rules

Safety rules specific to the injection operation should be provided.

B.2.h. Impact Control

There are several environmental problems that should be prevented. Specific instructions on control measures should be included in the manual. Prevention programs for disease vector or rodent breeding areas should be provided as part of the O&M manual. Odor control measures should be explained even if proper stabilization processes and application procedures have been provided. Noise control measures are generally not a problem in rural areas. In exceptional cases, however, noise control programs should be provided.

B.2.i. Personnel

The manual should include a recommended staffing level and a description of the qualifications required and/or specialized training needs. There are no established manpower requirements because of variation in application time periods, loading rates, sludge solids concentrations, and type of application equipment. Personnel requirements must be considered on a case-by-case basis.

B.3. FARM MANAGEMENT

This section is required for those agencies who wish to conduct the farming operation with their own staffs and equipment.

B.3.a. Description of Equipment

The farming equipment including tractors, trucks, tillage equipment and harvesting equipment should be described and manufacturers operating and maintenance schedules included. Lubrication schedules should be part of the maintenance schedule.

B.3.b. Description of Facilities

The O&M manual should provide a complete description of the farm facilities including the equipment within each facility. One of the most important areas of a farming operation is the maintenance shop. There will be a large inventory of specialized equipment within this shop. Complete operation and maintenance instructions for this equipment should be included in the manual. Crop storage facilities generally consist of bins or buildings with little mechanical equipment other than the loading and unloading facilities. Maintenance instructions plus rodent control procedures should be provided.

These facilities are similar to crop storage except more specialized handling procedures must be delineated.

B.3.c. Crop Management

Instructions should be provided for each crop grown specifying planting and harvesting schedules. Recommended methods of tillage, weed control, and pest control should also be included. Crop marketing practices should also be discussed. Supplemental fertilizer computation procedures should be delineated. Methods for adjusting pH should be shown.

Each item in the above section should be discussed for each crop grown. Recommended crop rotation schedules should be provided along with a discussion of changes in application procedures necessary to adjust to different crops. Recommended areas requiring specialized expertise should be outlined. The agency can then be prepared to obtain consulting services as recommended. The O&M manual should provide guidance on how to obtain custom or contract harvesting. A sample contract or contract format should be provided with the manual.

B.3.d. Contingency Procedures

There are two areas where emergency procedures or contingency plans are required. They are related to equipment operation and crop disease control. Farm equipment breakdown can be considered an emergency if this breakdown occurs at planting time or at harvest. The O&M manual should provide guidance on how to continue or modify operations with alternate equipment. Unusual problems will require a specialist but there are many problems that can be identified with minimal training. These problems include pests, weeds, nutrient deficiencies, and poor drainage. This information should be included in a troubleshooting format.

B.3.e. Emergency Procedures

The two major emergency conditions that can develop with the farming operation (not related to equipment) are discovery of excessive contaminants and extremely cold or wet weather.

If sludge or soil monitoring shows unacceptable levels of heavy metals or other contaminants, then the sludge must be applied at a lower rate or application site shifted to another area. Changes may also be made at the treatment plant to modify these concentrations. Plans for operating under these circumstances should be included in the O&M manual.

Some climate extremes such as cold or wet weather can result in operational problems or a major crop loss. For example, when faced with late spring, it may be useful to switch from corn to soybeans or sorghum to make use of the shorter season. These circumstances and the solutions to minimize losses should be discussed in the manual.

B.3.f. Personnel

Personnel requirements are somewhat complicated due to the seasonal nature of farming. The manual should show the number of personnel required for each farming task. Along with this the timing of each task should be provided. This should be shown in such a manner that seasonal variations can be easily recognized. Along with the personnel requirements listed above, individual qualifications should be shown. If special training is required, this should be shown also.

B.4. MONITORING

A complete monitoring program should be established. Background conditions should be determined so that the effects of land application can be assessed.

B.4.a. Parameters to be Measured

Soils monitoring may include pH, CEC, nitrogen, phosphorus, potassium, and heavy metals (Cd, Cu, Zn, Pb, Ni). The nutrient analyses are useful for good crop growth and for preventing excessive amounts of nitrogen or phosphorus in succeeding applications or for determining additional nutrient needs. Potassium is not normally a problem but monitoring is necessary to determine additional needs for good crop growth. The pH, CEC and metals determinations are useful for preventing metals accumulations in soils or crops. Pathogen monitoring should be as specified by the regulatory agency.

Crop monitoring should include yield, crop disease, and crop pest evaluations. Tissue analysis may be required periodically for food-chain crops. Crops destined for human consumption should be monitored for pathogens.

Surface waters and intermittent streams (when flowing) should be monitored as required by the appropriate regulatory agencies. Monitoring points should include at least one sampling station upstream of the application area and one downstream from the application area. Frequencies depend on circumstances of each site. Minimum parameters include BOD_5, suspended solids, nutrients, and coliforms. Nearby domestic wells should be tested prior to project startup and then monitored periodically. On-site monitoring wells should be placed and sampled as required by the appropriate regulatory agency. At a minimum, tests should include nitrates, total dissolved solids and coliforms.

B.4.b. Procedures

The procedures for sample collection and analysis should be clearly outlined in the operations guide. These will vary depending on the specific chracteristics of the site, but for any site, they should be closely followed.

B.4.c. How to Use Results

The results of the monitoring and sampling program will be used to assess the operation. The interpretation of the data collected can indicate the success of the current operation, may lead to develop procedural changes to improve or streamline activities, suggest design modifications and provide a useful tool in planning future expansions. Based on the monitoring reports, a complete and through assessment of operations should be made periodically.

B.4.d. Reporting Procedures

The operators should be familiar with the reporting requirements and procedures outlined in the operating permits. Submitting regular reports to the various agencies having jurisdiction over the operation is important. The operators should be fully aware of the penalties involved in failure to do so.

Sample reports and record-keeping practices should be available to the operators. All data, logs and reports should be kept in an orderly manner in a safe place.

Section C - LANDFILL

The successful operation of a sludge landfill is a relatively straightforward task although it requires attentive surveillance. The following sections describe the information and procedures necessary to operate and properly maintain a sludge landfill.

C.1. PERMITS AND STANDARDS

Numerous permits are required to operate a landfill. As well, certain standards must be upheld and reporting procedures for non-compliance are clearly specified.

C.1.a. Solid Waste Disposal

The information pertinent to operating the landfill which is specified in the solid waste disposal permit should be readily available. The operators should be familiar with specific information such as the issuing agency, permit number, renewal date and specific requirements. In addition, they should be aware of more general information such as permit application guidelines and laws and regulations pertaining to sanitary landfill operations.

C.1.b. Discharge Permits for Runoff and Leachate

Permits will be required for the discharge of all uncontained and treated runoff and leachate. The operators should be familiar with the permit, including such information as the number, renewal date and specific requirements contained in it. Copies of all permits should be readily available for reference. Information such as application guidelines and general requirements should be available to operators.

C.1.c. Reporting Procedure for Spills of Raw or Inadequately Treated Wastewater

All violations of discharge requirements must be reported to the jurisdictional agency. The reporting procedures and emergency phone number should be clearly posted and the operators familiar with them. A sample report format should be available. The owner and operators should be informed of their responsibilities for violating the discharge standards and the possible penalties which could be levied.

C.1.d. Water Quality Standards

It is the responsibility of the operating agency to conform to the quality standards of any waters affected by the landfill operation. The operators should be aware of local streams receiving runoff from the landfill and of their classifications and beneficial uses. Particular care should be taken to prevent the accidental pollution of quality sensitive streams or water supplies near the landfill.

C.2. DESCRIPTION OF LANDFILL

A detailed description of the landfill will be useful to the regular operators, new or substitute operators, owners, jurisdictional officers and consultants. This should include narrative and graphical information defining the method landfill operations, the design criteria, the site and unusual or outstanding features. A general description of the normal and emergency operating procedures should be included. The description of the landfill should be simple and clear enough for a non-technical audience yet comprehensive enough for those more familiar with such systems.

C.3. RELATIONSHIP TO OTHER UNIT PROCESSES

Landfill is the last step in an often complex chain of wastewater and sludge treatment processes. In order to fully understand its function and operation, the operators should be aware of its relationship with these other processes.

C.3.a. Pretreatment Processes

The processes upstream of landfilling will determine the nature and quantity of sludge to be disposed of. The operators should be aware of what these processes are and how their operation or elimination will affect the sludge characteristics and landfill operations.

C.3.b. Sludge Transport

The sludge transport operations directly influence the landfill operations. Ideally, a more-or-less continuous or at least regularly scheduled delivery of sludge should be expected at the landfill. The landfill operators should be informed of any variations in the transport schedule and alerted to any emergencies so their operations can be modified accordingly.

C.3.c. Runoff and Leachate Treatment

If runoff and leachate treatment facilities are located at the landfill site, the operators should be familiar with them. If these flows are pumped or trucked to an off-site location for treatment the operators should be familiar with the transport system.

C.3.d. Co-disposal With Refuse

If sludge is to be included in a refuse landfill, close coordination will be necessary. A clearly defined disposal plan and a regular transport schedule will simplify operation and reduce the potential problems associated with combining the two operations.

C.4. MAJOR COMPONENTS

The successful operation of a sludge landfill depends, in part, on the understanding and operation of ancillary facilities and equipment. These must be maintained to insure reliable operations.

C.4.a. Facilities

The operating staff should be familiar with the operation and maintenance of all facilities at the landfill site. In addition to the manufacturer's O&M instructions, an operations manual should be available and reviewed periodically. It should include such information as a regular maintenance checklist, a troubleshooting guide, an emergency operation plan and safety guidelines. Features such as leachate, runoff and gas controls, roads, soil stockpiles and inclement weather areas are essential to the day-to-day operation of the landfill. Other facilities such as offices, utilities and equipment yards are provided for the operators' comfort and convenience; these must be maintained in the interest of safety and aesthetics. Monitoring wells and equipment are to safeguard the public health, protect against adverse environmental impacts and to aid in future operations planning; these should be maintained and operational at all times.

C.4.b. Equipment

The mechanical equipment for periodic and day-to-day operations such as excavation, sludge handling, and processing, filling and cover must be operational at all times. Daily maintenance checks and preventive repairs are a necessity. Periodic troubleshooting can reduce the unscheduled downtime of this equipment and minimize costly work stoppages. Maintenance and operations schedules should be carefully planned, clearly posted and followed as closely as possible.

C.5. MONITORING

A complete monitoring program should be established prior to the startup of a sludge landfill. Background conditions should be determined so that the operation and effects of the landfill can be assessed.

C.5.a. Parameters to be Measured

It is possible to measure numerous parameters at a landfill site, however, only those features yielding useful information should be studied. The characteristics of the sludge such as source, solids content, quantity application, location, etc. should be recorded daily. The quantity and quality of leachate and runoff should also be measured. Climatic conditions should also be noted.

The number and type of monitoring wells is highly site-specific. It is essential that these wells be sampled according to the specified schedule. Maintaining surface and groundwater quality is an essential task associated with landfill operations.

C.5.b. Procedures

The procedures for sample collection and analysis should be clearly outlined in the operations guide. These will vary depending on the specific characteristics of the landfill, but for any site, they should be closely followed.

C.5.c. How to Use Results

The results of the monitoring and sampling program will be used to assess the landfill operation. The interpretation of the data collected can indicate the success of the current operation, may lead to develop procedural changes to improve or streamline activities, suggest design modifications and provide a useful tool in planning future expansions. Based on the monitoring reports, a complete and through assessment of operations should be made periodically.

C.5.d. Reporting Procedures

The operators should be familiar with the reporting requirements and procedures outlined in the operating permits. Submitting regular reports to the various agencies having jurisdiction over the landfill is important. The operators should be fully aware of the penalties involved in failure to do so.

Sample reports and record-keeping practices should be available to the operators. All data, logs and reports should be kept in an orderly manner in a safe place.

C.6. STARTUP PROCEDURES

Several steps are necessary in starting up a sludge landfill. These will vary with the site and type of fill operation, however certain basic practices should be followed. During operation it would be prudent to check nearby aquifers and surface waters against the original background conditions to be sure that operations have not adversely affected their quality. The initial work site must be prepared according to the landfill plan. This work will depend on the method of fill to be used and the measures designed for environment impact mitigation. The initial trench dimension should be in accordance with the filling plan. Depending on the degree of success of the startup operations, the trench size may be kept the same or modified somewhat. A soil stockpile should be established at the landfill site. Depending on the method of operation, the stockpile will be composed of native soil excavated during initial trenching, imported soil to be used as a bulking agent or cover, or a combination of the two. The stockpile should be in a convenient location for both normal and inclement operations. Trench liners may be an essential element in the landfill design. Whether constructed of soil, or natural or artificial material they must be carefully placed prior to filling. The liner specifications should be followed and an inspection made before any lined trenches are used.

C.7. NORMAL OPERATION

After initial startup, normal operations should follow a simple, routine set of procedures. These will vary depending on the method of filling and may need to be modified periodically. The operators should be informed of any modifications and instructed on operational changes.

C.7.a. Trench, Fill, or Berm Locations

After the initial startup the landfill operation should follow a logical fill sequence. The operators should be instructed on the location of subsequent fill areas. A plan of these areas should be included in the O&M instruction manual and periodically reviewed by the operators.

C.7.b. Trench, Fill, or Berm Dimensions

The size of the fill areas should roughly duplicate those initially created; they may, however, vary depending on the terrain. The filling plan included in the operators' manual should clearly specify any deviation in the established operating scheme.

C.7.c. Handling of Soil Removed from the Trench

Native material excavated during trenching should be stockpiled for future use as a bulking agent or cover material. The stockpile location should be convenient and near the area where it is to be used. The methods for removing, placing, and storing this material should be described in the O&M manual.

C.7.d. Imported Soil

The type and quantity of imported soil, if any, should be described in the operations guide. If more than one type of soil is to be used at the landfill, the stockpiles should be clearly identifiable and separate.

C.7.e. Co-disposal Procedures

The procedures for co-disposal of sludge and refuse, if practiced, should be clearly delineated in the operating instructions. The operators should be instructed on the procedures for mixing the sludge and refuse as well as for the actual filling operations.

C.7.f. Liners

Since liners are critical to the long-term operation of a landfill, if they are required at all, their placement and maintenance is an important operational item. The materials and procedures for constructing liners should be clearly described in the O&M manual; the operators should be made familiar with this information.

C.8. EMERGENCY OPERATION AND FAIL-SAFE FEATURES

A contingency plan for emergency operation should be included in a separate section of the O&M manual.

C.8.a. Inclement Weather Operations

In general, the procedures for operation in inclement weather should follow the same basic steps as normal operation. The difference in the operation is the location of the fill. A separate fill area with paved or all-weather roads is designated for use during inclement weather. This area is generally located near the main entrance to the landfill to minimize the sludge haul distance. Any special procedures for using this portion of the site or for filling when the weather is bad should be identified and easily found in the O&M manual.

C.8.b. Gas Control

The accumulation of gas produced during filled sludge decomposition can present a hazard at the fill site. Methane is particularly dangerous since it is explosive under certain conditions.

The gas control systems should be completely described in the O&M manual. Emergency operations should be reviewed periodically so the operating staff is familiar with them. Regular maintenance and monitoring will reduce the potential for emergency operations. This cannot be overstressed in the operation and maintenance manual, in operator training sessions, or on the job.

C.9. LANDFILL COMPLETION

In completing a sludge landfill, a certain set of criteria must be met to make it publically acceptable. These criteria will be established according to the type of landfill and the location, size and ultimate use of the site. The procedures for site closure should be included in the operations manual and updated or modified if the original landfill plan is not followed.

C.9.a. Ultimate Use

The ultimate use of the site should be described and illustrated in the O&M manual or a separate document which describes the completion of the site. The actual work involved in completing the site will depend on its ultimate use and on the care taken in day-to-day fill operations.

C.9.b. Grading at Completion of Filling

When each section of the landfill is complete, the final cover should be graded according to a pre-determined plan. It is imperative that no sludge become or remain exposed after the grading has been completed.

C.9.c. Final Grading

The final grading is to be performed after a sufficient period of time has passed for initial settlement to have occurred. The final grading plan will be designed according to the ultimate intended use of the landfill site. It is important that all sludge be completely covered with the prescribed depth of cover material.

C.9.d. Landscaping

The landscaping plan should reflect the intended ultimate use of the landfill site. Where practical, landscaping may be done on completed sections prior to the completion of the entire fill project.

C.9.e. Continued Leachate and Gas Control

Since decomposition of the organics in the sludge may continue even after the landfill has been completed, an ongoing monitoring and control program must be maintained. Leachate and gas must be controlled even after the filling operations have stopped. A program for doing this should be clearly outlined in the completion plan.

C.10. SAFETY

Providing a safe working environment at the landfill should be a part of the general O&M of the site. Certain safety features will be a part of the design, however, day-to-day practices to provide safe working conditions must also be followed. The O&M manual should have a separate safety section as well as specific safety guidelines for each operation and feature of the landfill.

C.10.a. Soil Stability

The stability of the soil at the fill site, particularly near the work areas can present a critical safety problem, particularly with the use of large equipment. The bearing strength of all disturbed areas should be checked prior to moving fill equipment on them. Caution should be used when approaching muddy areas or those subject to erosion.

C.10.b. Equipment Operation

The operation of large earth moving equipment presents the potential for numerous minor and major accidents. Only fully trained operators should be allowed to operate such equipment. Regular maintenance and safety checks can greatly reduce the number of accidents associated with equipment failure.

C.10.c. Gas Control

Caution must be practiced when dealing with gas control equipment. Methane gas can be highly explosive. The O&M manual should contain a complete set of instructions on the safe servicing of gas control and monitoring equipment. Verbal instruction on the operation of this equipment should be given periodically at operation and safety training sessions.

C.11. IMPACT CONTROL

The protection of the environment and of the public health are important aspects of the landfill operation which cannot be overlooked. The O&M manual should contain guidelines for providing this protection and the actual operation should reflect these practices.

Environmental protection is generally focused on leachate and runoff controls to prevent surface and groundwater contamination. Trench liners must be kept intact during and after filling operations. Drainage systems should be checked to see that they are functioning as designed. If monitoring shows that adverse environmental impacts have occurred or pose a threat, immediate action should be taken to mitigate them.

Protection of public health should be a foremost concern in the operation of sludge landfills. Protection of water supplies and sole source aquifers is an obvious responsibility. In addition, the control of disease by the reduction of vectors such as flies, the adequate venting of explosive or toxic gases, and the restriction of access to the landfill site are the responsibility of the operators.

Minimizing the aesthetic impacts of a sludge landfill can greatly increase the public acceptability of such a project. The control of odors, noise and other nuisances is generally straightforward and can be accomplished as part of the daily operating routine. All efforts should be made to reduce the social impacts of the fill operation particularly if the site is located in an accessible or populated area.

C.12. PERSONNEL

The personnel requirements will vary depending on the specific features and size of the landfill operation. Adequate personnel should be maintained to fill all functions of the operation and allow for vacation relief and emergencies. The staff should be properly trained to perform their primary duties and should be familiar with the other operations at the site. Regular training sessions and safety incentive programs will encourage efficient landfill operations.

Section D - COMBUSTION

D.1. PERMITS AND STANDARDS - AIR DISCHARGE PERMITS AND PERMIT REQUIREMENTS

All applicable federal, state and local emission limitations and permit requirements should be fully explained in the operation and maintenance manual. Included should be permit numbers, renewal dates, permit requirements and instructions for making renewal applications and a summary of all federal, state, local, or regional laws and regulations pertaining to the operation of incinerators.

D.2. DESCRIPTION OF FACILITY

D.2.a. Design Criteria

The facility description must include a summary of the system design criteria:

- Anticipated minimum, maximum, and average sludge loading rates
- Anticipated sludge characteristics, especially moisture and heat contents
- Design criteria which relate to air pollution, such as temperatures and detention times
- Design criteria for the energy recovery systems, including operating temperatures, uses, and anticipated yields

D.2.b. Process Description

The facility description should include a description of the combustion process used. The process description should follow the sludge through the combustion process, explaining the reactions that take place. For example, a multiple hearth incinerator description would describe the drying, combustion and cooling zones; the action of the rabble arms; and the flow of sludge and air through the reactor.

D.3. RELATIONSHIP TO OTHER PROCESSES

The relationships of the combustion process to the other wastewater and sludge treatment processes must be explained. Included in the explanation should be parameters for optimizing the relationships between the combustion process and the related unit processes.

D.3.a. Pretreatment Processes

The relationship of the sludge pretreatment processes to the combustion process must be outlined. Typical relationships which should be discussed are:

- The effects of thickening and dewatering system efficiency on moisture content and fuel consumption
- The effects of chemical addition on moisture content, heat content, fuel consumption, and ash volume
- The effects of wastewater treatment process operation on sludge volumes and characteristics

The combustion system sidestreams such as wet-air oxidation liquor and scrubber effluent water on wastewater treatment processes should be explained.

Consideration should be given to the effects of the rest of the unit processes on the ash disposal system, including:

- Sludge production from wastewater treatment processes
- Increases in ash quantities from chemical conditioning processes
- Effects on ash quantity and quality of combustion process operation

Where co-disposal with municipal refuse is to be practiced, the operating parameters of the refuse processing system must be explained. Data concerning the approximate ratio of solid waste to sludge expected or desired, and the composition and quality (i.e., degree of classification, particle size, moisture content and heat content) of the refuse should be identified.

D.4. MAJOR COMPONENTS

Each of the major components of the combustion process should be described in detail, identifying the design criteria and critical operating parameters of each item or system. The major items or systems which should be included are:

- Sludge charging system, including pumps, grinders, and conveyors
- Process reactor or furnace
- Auxiliary fuel supply and control systems
- Combustion, cooling, fluidizing and wet-air oxidation air supply systems
- Wet-air oxidation steam supply systems
- Energy recovery systems, including heat exchangers, turbines, etc.
- Air pollution control equipment
- Ash handling and disposal systems

D.5. MONITORING

The operation and maintenance manual should include a detailed program for the combustion process. The monitoring program should cover those parameters which affect compliance with federal, state, regional and local air quality requirements as well as those which pertain to incinerator operation. Figure 17 illustrates a typical monitoring program for a multiple hearth incinerator.

SUGGESTED MINIMUM

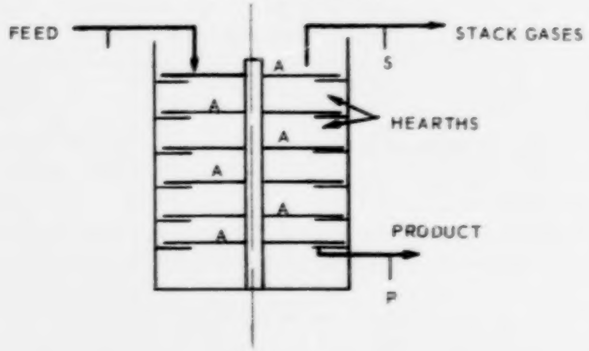
OPTIONAL

	PLANT SIZE (MGD)	TEST FREQUENCY	LOCATION OF SAMPLE	METHOD OF SAMPLE	REASON FOR TEST
TEMPERATURE		Mn	A	Mn	P
TOTAL VOLATILE SOLIDS		$1/D^1$	F P	G	P
TOTAL SOLIDS		$1/D^1$	F P	G	P
STACK GAS COMPOSITION	Z	Z	S	Z	R

ESTIMATED UNIT PROCESS SAMPLING AND TESTING NEEDS

INCINERATION

(MULTIPLE HEARTH)



A. TEST FREQUENCY

H = HOUR
D = DAY
W = WEEK
M = MONTH
R = RECORD CONTINUOUSLY
Mn = MONITOR CONTINUOUSLY

B. LOCATION OF SAMPLE

I = INFLUENT
E = EFFLUENT
S = STACK GASES

C. METHOD OF SAMPLE

24C = 24 HOUR COMPOSITE
G = GRAB SAMPLE
R = RECORD CONTINUOUSLY
Mn = MONITOR CONTINUOUSLY

D. REASON FOR TEST

H = HISTORICAL KNOWLEDGE
P = PROCESS CONTROL
C = COST CONTROL
R = TO MEET REGULATIONS

E. FOOTNOTES:

1. THESE TESTS SHOULD ALSO BE RUN ON RECEIVING WATER, ABOVE AND BELOW OUTFALL, ON A PERIODIC BASIS, DEPENDING ON LOCAL CONDITIONS.
2. AS REQUIRED TO MEET AIR QUALITY STANDARDS

Figure 17. Typical multiple hearth furnace monitoring program.

D.5.a. Parameters

Sludge monitoring should include total sludge flow, total solids, and total volatile solids. Additional monitoring may be required by air quality regulations, such as mercury or PCB content. Stack emission monitoring should be in accordance with air quality regulations. In addition to the data required by air quality authorities, such information as carbon monoxide and hydrocarbon content are often useful in analyzing reactor performance. Temperatures are the critical parameters in reduction system operation. Temperature is usually monitored continuously at several points in the process. These monitoring points should be in accordance with the combustion process manufacturer's recommendations. Monitoring of combustion air, cooling, air, fluidizing air, or wet-air oxidation air flows is often useful and should be included in the monitoring program if recommended by the manufacturer. Fuel consumption records are valuable in optimizing the operation of the combustion and dewatering processes.

D.5.b. Procedures

The manual should explain all monitoring and record-keeping procedures, including sampling frequencies, methods, and locations. Laboratory procedures should include step-by-step instructions together with reference to the appropriate chapters in Standard Methods for the Analysis of Water and Wastewater (9) or other laboratory desk reference.

D.5.c. Using Results

The operation and maintenance manual should explain the purpose and use of each test. Where monitoring is for operational parameters, explanation should be included as to the control actions which should be taken in response to the measurements.

D.5.d. Reporting Procedures

The manual should include detailed instructions for reporting required data to regulatory agencies. The agency, required parameters and reporting frequency should be identified. Sample record and reporting forms are valuable aids to the operator and should be included.

D.6. STARTUP

The startup procedures should include a sequence of operations for starting the combustion system, maximum safe heating rates for reactors, expected auxiliary fuel consumption and operating temperatures which must be attained before operation can begin.

D.7. NORMAL OPERATION

Normal operating procedures should include the economical range of sludge feed rates, the range of air supply rates, the range of auxiliary fuel consumption rates, normal operating temperatures, and operating parameters for putting the reactor on standby status during periods of low sludge flows, or at night for daytime-only operations.

D.8. EMERGENCY OPERATION AND FAIL-SAFE FEATURES

A description of emergency procedures should be included, including the actions to be taken in the event any component of the combustion system experience a mechanical failure. The emergency procedures should identify the amount of time expected to be available for corrective action and advise the operator of any consequential problems which may result. This section of the manual is the appropriate place to describe facilities for improving reliabilities such as:

- Standby power
- Standby fuel
- Duplicate process units
- Alternative sludge management systems

D.9. SHUTDOWN

Shutdown procedures should include a detailed sequence of operations for shutting down the combustion system, maximum safe cooling rates for reactors and expected auxiliary fuel consumption during cooling.

D.10. SAFETY

Detailed safety procedures should be described for the combustion system. Most safety requirements are those generally applicable to wastewater treatment plants, but certain additional safety factors should be called to the operator's attention. The flame safety system's purpose, operation and features should be called to the operator's attention. Special instructions should be included for the safe use of the auxiliary fuel and associated equipment.

Safety rules for the reactor should be outlined, including such things as the use of air masks within the reactor and viewing burning sludge only through smoked glass.

D.11. IMPACT CONTROL

The manual must identify for the operator those operating parameters which are vital to minimizing deleterious environmental impacts. Most of these parameters relate to air quality or odor control and include such things as maintaining adequate excess air supply, insuring adequate incineration temperatures and gas detention times, and adequate maintenance of air pollution control equipment.

D.12. PERSONNEL

The manual should outline operating and maintenance personnel requirements for the combustion and energy recovery systems. Manpower requirements for incineration are given in reference 71. Emphasis should be given to any special qualifications or training recommended by the equipment manufacturers. Certain energy recovery equipment may require a qualified stationary engineer, for instance.

Section E - PROCESS FOR OFF-SITE USE OF SLUDGE BY OTHERS

E.1. PERMITS AND STANDARDS

All applicable federal, state and local emission limitations and permit requirements should be fully explained in the operation and maintenance manual. Included should be permit numbers, renewal dates, permit requirements and instructions for making renewal applications and a summary of all federal, state, local, or regional laws and regulations pertaining to the operation of flash dryers or incinerators.

The manual should include a summary of all federal, state and local requirements concerning the sale or use of sewage sludge as fertilizer. Some states restrict the use of sludge to certain applications. Other states establish minimum nutrient levels for a product to be termed "fertilizer". Sludge products not meeting the minimum requirements may be required to be labeled as "soil conditioner". Requirements for labeling of bagged product should be summarized, and any necessary warning labels identified. The requirements for establishing the nutrient analysis of the product (nitrogen, phosphorus and potassium) should be presented together with the labeling requirements.

E.2. DESCRIPTION OF FACILITY

E.2.a. Design Criteria

The facility description should include a summary of the design criteria for the system. The summary should include, as a minimum, the following information:

- Anticipated minimum, average, and maximum sludge loading rates
- Anticipated sludge characteristics including moisture, nitrogen, phosphorus, potassium, heavy metals, toxic organic compounds, and pathogens
- Bulking agent description and anticipated consumption rate (composting)
- Anticipated product production rate
- Anticipated product characteristics, including those items listed for sludge.

E.2.b. Process Description

The facility description should include a detailed description of the process. The description should follow the sludge through the process, describing the reactions that take place. A windrow composting process description, for example, would describe mixing with the bulking agent, construction of windrows, the aerobic digestion process known as composting, windrow turning, curing and screening.

E.3. RELATIONSHIP TO OTHER UNIT PROCESSES

The relationship of the sludge processing system to other wastewater and sludge treatment processes must be explained in detail. Included in the description should be parameters and procedures for optimizing the relationships among the processes.

The effects of the operation of the wastewater treatment system on the quantity and quality of product should be discussed in detail.

The relationship of the sludge and product transport systems to the process should be explained, together with information on optimizing the delivery and removal time for sludge and product.

The effects on the wastewater treatment process of the return or sidestreams should be explained. Among the sidestreams of concern are:

- Composting process runoff
- Flash dryer scrubber effluent
- Lagoon supernatant
- Drying bed underflow

For flash drying using dried sludge as fuel systems the effects on ash production of various production rates and operating modes should be explained. If ash is returned to the wastewater treatment process, the effects of the increased load on the treatment process should be explained.

Where co-composting with municipal refuse is practiced, the operating parameters of the refuse processing system must be explained. Data concerning the approximate ratio of sludge to solid waste expected or desired, the composition and quality (i.e. degree of classification, particle size and moisture content of (i.e. moisture content and nutrient analysis) of the sludge should be identified.

E.4. MAJOR COMPONENTS

The major components of the system should be described in detail, identifying the design criteria and critical operating parameters of each item or system. Major items and systems which should be included are:

- Mixing (composting)
- Aerating (composting)
- Handling
- Screening (composting)
- Drying beds or lagoons
- Ash disposal (flash drying)
- Auxiliary fuel (flash drying)
- Air supply (flash drying)
- Air pollution control (flash drying)
- Nutrient enrichment

E.5. MONITORING

The operation and maintenance manual should include a detailed monitoring program for the process. The program should include those parameters which affect compliance with federal, state, regional and local air quality requirements, those which pertain to the safety and utility of the final product, and those which pertain to system operatión.

E.5.a. Parameters

Sludge monitoring should include:

- Total sludge flow
- Total solids
- Total volatile solids
- Monitoring required to assure safety such as heavy metals, PCB's and pathogens
- Additional monitoring required by air quality requirements
- Nutrient content including nitrogen, phosphorus and potassium

Product parameters which should be monitored include:

- Production
- Bulk density
- Moisture content
- Nutrient content including nitrogen, phosphorus and potassium
- Monitoring required to assure safety such as heavy metals, PCB's and pathogens

Stack emission monitoring should be in accordance with air quality regulations. In addition to the data required by air quality authorities, such information as carbon monoxide and hydrocarbon content are often useful in analyzing flash dryer performance.

Compost pile temperatures should be monitored to assure a proper rate of stabilization. Temperatures should be taken at the inside of the compost pile.

Temperatures are the critical parameters in flash dryer system operation. Temperature is usually monitored continuously at several points in the process. These monitoring points should be in accordance with the dryer manufacturer's recommendations.

Oxygen readings indicate the performance of the composting operation and serve as the basis for turning windrows and adjusting aeration blowers for static pile composting.

In static pile composting, monitoring of air flows may be useful in assessing system performance. This can be most easily accomplished by monitoring blower running time.

Monitoring of combustion air flows is often useful and should be included in the monitoring program if recommended by the dryer manfacturer.

Fuel consumption records are valuable in optimizing the operation of the flash drying processes.

E.5.b. Procedures

The manual should explain all monitoring and record-keeping procedures, including sampling frequencies, methods, and locations. Laboratory procedures should include step-by-step instructions together with references to the appropriate chapters in Standard Methods for the Analysis of Water and Wastewater (9) or other laboratory desk reference.

E.5.c. Using Results

The operation and maintenance manual should explain the purpose and use of each test. Where monitoring is for operational parameters, explanation should be included as to the control actions which should be taken in response to the measurements.

E.5.d. Reporting Procedures

The manual should include detailed instructions for reporting required data to regulatory agencies. The agency, required parameters and reporting frequency should be identified. Sample record and reporting forms are valuable aids to the operator and should be included.

E.6. STARTUP

The startup procedures should include a sequence of operations for starting the process. This is particularly true for flash drying systems which should include such data as maximum safe heating rates for reactors, expected auxiliary fuel consumption and operating temperatures which must be attained before operation can begin.

Manuals for composting and bed and lagoon drying systems may be able to omit separate startup instructions as the startup of these systems may be indistinguishable from normal operation.

E.7. NORMAL OPERATION

Normal operating instructions for sludge processing systems should identify the economical range of sludge feed rates and product packaging and loading instructions. Composting system descriptions should also include:

- Mixing instructions, including sludge-to-bulking agent ratios
- Windrow or static pile construction instructions, including dimensions
- Windrow turning instructions and frequency
- Static pile aeration schedules
- Normal range of pile temperatures
- Composting time
- Windrow or static pile removal instructions
- Curing instructions
- Curing time
- Screening instructions
- Bulking agent recycle instructions

Flash drying systems should include the following instructions:

- The normal range of air supply rates
- The normal range of auxiliary fuel consumption
- Normal operating temperatures
- Instructions for putting the system on standby status

Lagoon and bed drying system instructions should include expected drying times and sludge removal procedures.

E.8. EMERGENCY OPERATION AND FAIL-SAFE FEATURES

A description of emergency procedures should be included, including the actions to be taken in the event any component of the processing system experiences a mechanical failure. The emergency procedures should identify the amount of time expected to be available for corrective action and advise the operator of any consequential problems which may result. This section of the manual is the appropriate place to describe facilities for improving reliabilities such as:

- Standby power
- Standby fuel
- Duplicate process units
- Alternative sludge management systems
- Availability of back-up equipment from other sites or agencies, or from rental agencies.

E.9. SHUTDOWN

The shutdown procedures should include a sequence of operations for shutting down the process. This is particularly true for flash drying systems which should include such data as maximum safe cooling rates for reactors, expected auxiliary fuel consumption during cooling.

Manuals for composting and bed and lagoon drying systems may be able to omit separate shutdown instructions as the shutdown of these systems may be indistinguishable from normal operation.

E.10. SAFETY

Detailed safety procedures should be described for the processing system. Most safety requirements are those generally applicable to wastewater treatment plants, but certain additional safety factors should be called to the operator's attention.

A flash dryers flame safety system's purpose, operation and features should be called to the operator's attention. Special instructions should be included for the safe use of the auxiliary fuel and associated equipment. Safety rules for the reactor should be outlined, including such things as the use of air masks within the reactor and viewing burning only through smoked glass. Dust is a particular safety and maintenance problem for flash drying systems. The process product is a very dry, finely divided, light, abrasive, combustible dust. The dust can be highly explosive and can also cause equipment failures due to its abrasive nature. Adequate measures must be detailed in the manual to insure control of the dust.

Manuals for composting operations should include safety rules for the operation of heavy construction equipment.

E.11. IMPACT CONTROL

The manual must identify for the operator those operating parameters which are vital to minimizing deleterious environmental impacts.

Environmental impact control relates primarily to air quality control from flash drying processes and runoff control from composting operations. Air quality control can be enhanced by the operator by maintaining an adequate excess air supply to the dryer furnace, insuring adequate burning temperatures and detention times, adequate maintenance or air pollution control equipment, and proper dust control procedures. Health impacts of sludge processing systems include the safety of the finished product and control of disease vectors at the site. The safety of the finished product is to a large degree, a function of the composition of the sludge entering the process. The pathogen component can, however, be greatly affected by the operation of the process. Proper composting and flash drying operation can greatly enhance product safety. Disease vectors are potentially troublesome in drying bed, drying lagoon and composting operations and detailed measures for their control should be included in the operation and maintenance manual.

Social impacts such as odors, noise and dust are potential problems for sludge processing systems, and adequate measures for their control should be identified. Odors are usually minimized by proper operation of the process while the effects of noise can often be minimized by scheduling of operations.

Dust is a particular problem in flash drying systems and its control is essential to successful operation.

E.12. PERSONNEL

The manual should outline operating and maintenance personnel requirements for the sludge processing system (See references 71 and 72 for personnel requirements for composting, sandbeds and sludge lagoons). Emphasis should be given to any special qualifications or training recommended by equipment manufacturers. Composting operations, for instance, will require a qualified heavy equipment operator.

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APPENDIX A

DESIGN OF LAND APPLICATION SYSTEMS FOR AGRICULTURAL UTILIZATION OF SEWAGE SLUDGE

INTRODUCTION

Utilization of sludge as a soil amendment can be very beneficial to crop growth or, if mismanaged, can have disastrous results. Benefits include the addition of nitrogen, phosphorus, and organic matter. Nitrogen and phosphorus are necessary plant nutrients. Organic matter improves drainage of clay soils and moisture holding capacities of sandy soils. Tillage characteristics of soils are also improved. Generally, the soil conditioning properties of sludge are more significant than the nutrient additions. Mismanagement of a land application system can result in public health problems, odor nuisances, and/or soil destruction from excessive heavy metal buildup. A land application system must be designed to provide maximum benefits from the sludge without creating problems. The design should therefore include rate determination schedules and methods to be used by operators. Monitoring requirements should also be specified to help prevent nuisance conditions from developing. This appendix has been developed with emphasis on the agricultural management aspects rather than the public health The procedure used is similar to one in Reference 21.

Sludge Analysis

Prior to applying sludge to cropland, the following tests should be run:

Sludge Analyses

- Nitrogen content and forms
    - Organic nitrogen
    - Ammonia
    - Nitrates
- Phosphorus
- Potassium
- Heavy metals
    - Cadmium
    - Lead
    - Copper
    - Zinc
    - Nickel
- Percent solids
- Tests required by local health agencies

These tests should be run monthly for three to six months prior to starting the land application system so that averages can be computed. After the system has begun operation, annual monitoring should be continued so that changes in constituent levels can be detected and application rates adjusted.

Site Preparation

Prior to applying sludge to a particular site, the soil should be tested for pH, cation exchange capacity, and phosporus and potassium availability. The existing crops grown should be reviewed for adaptability to sludge amended soils. If an unacceptable crop is being grown (e.g., a raw vegetable), then another crop would be required. Crop selection would have to be consistent with local farming practices and locally marketable.

Futher site preparation can then be done after a crop or crops have been chosen. Site work includes drainage control, monitoring wells, pH adjustment by lime addition (if necessary), and field preparation fot eh crop to be grown. Drainage control is essential for good agricultural practice as well as protection of downstream water quality. In general, natural drainage courses should be left undisturbed. If a drainage course passes through a site, field runoff should be diverted but the drainage course left in place. Runoff from adjacent areas should be diverted around the land application site.

Monitoring wells should be placed throughout the site. Depth of well would be based on ground water location. Location of well is usually based on site layout and groundwater flow direction. Diameters should be large enought to provide easy sampling.

pH adjustment is generally necessary for those soils with pH values less than 6.5. The adjustment is usually accomplished by lime addition.

Field preparation is the tillage required for crop planting. If sludge is surface spread, then field preparation will usually follow immediately so that the sludge is tilled into the soil.

Application Rate Calculation

The application rate calculation is frequently based mainly on the nitrogen requirements of the crop to be grown. The computed rate is then adjusted, if necessary, to prevent excessive heavy metal or phosphorus buildups. A step-by-step procedure follows:

Step 1 Determine Application Rate by Nitrogen Balance

a. Analyze sludge nitrogen content. Determine organic nitrogen, ammonium nitrogen and nitrate nitrogen (if aerobically digested) concentrations. Typical nutrient contents for anaerobic sewage sludges are shown on Table A-1.

   For this example, assume the organic nitrogen is 80 lb/ton and ammonium nitrogen is 30 lb/ton.

b. Determine nitrogen requirement of the crop from Table A-2. For this example assume corn is grown (expected yield of 180 bu/acre). The nitrogen requirment is 240 lb/ac.

TABLE A-1. COMPOSITION OF REPRESENTATIVE ANAEROBIC SEWAGE SLUDGES (8)

Component	Range	Lb/ton**
Organic nitrogen	1% - 5%	20 - 100
Ammonium nitrogen	1% - 3%	20 - 60
Total phosphorus	1.5% - 3%	30 - 60
Total potassium	0.27% - 0.8%	4 - 16

*Percent of oven-dry solids
**Lb/ton dry sludge

TABLE A-2. ANNUAL NITROGEN, PHOSPHORUS, AND POTASSIUM UTILIZATION BY SELECTED CROPS*

Crop	Yield	Nitrogen	Phosphorus	Potassium
			Lbs. per Acre	
Corn	150 bu	185	35	178
	180 bu	240	44	199
Corn silage	32 tons	200	35	203
Soybeans	50 bu	257	21	100
	60 bu	336	29	120
Grain sorghum	8,000 lb	250	40	166
Wheat	60 bu	125	22	91
	80 bu	186	24	134
Oats	100 bu	150	24	125
Barley	100 bu	150	24	125
Alfalfa	8 tons	450	35	398
Orchard grass	6 tons	300	44	311
Brome grass	5 tons	166	29	211
Tall fescue	3.5 tons	135	29	154
Bluegrass	3 tons	200	24	149

* Note that this hypothetical illustrated case does not agree with Table 8 values. Values will vary with yield and regional crop practices.

c. Determine the amount of nitrogen available from mineralization of previously applied organic nitrogen and the amount that will be available from present application. Crops utilize nitrogen when it is in the ammonium or nitrate forms. Organic nitrogen must be converted to the ammonium ion before it can be utilized by the plant. The conversion or mineralization rate varies with climate and soil type, but a typical mineralization rate would be 20 percent the first year and 3 percent of the remaining organic nitrogen each year for subsequent years. The release rates of nitrogen by this process are shown on Table A-3 for different sludges.

TABLE A-3. RELEASE OF RESIDUAL NITROGEN DURING SLUDGE DECOMPOSITION IN SOIL

Year after sludge application	Organic N content of sludge, %						
	2.0	2.5	3.0	3.5	4.0	4.5	5.0
	Lb. N Released per Ton or Sludge Added						
1	1.0	1.2	1.4	1.7	1.9	2.2	2.4
2	0.9	1.2	1.4	1.6	1.8	2.1	2.3
3	0.9	1.1	1.3	1.5	1.7	2.0	2.2

The example sludge has 80 lb/ton organic nitrogen. Assume this is the fourth year of land application. The previous applications were at 10 tons/acre with sludge having an 80 lb/ton or 4 percent organic nitrogen content. The amount of available nitrogen is computed as follows:

Previous Year: 1.9(10) + 1.8(10) = 1.7(10) = 54 lb/acre
This Year: 30 lb/ton + 80 lb/ton x .20(% available) = 46 lb/ton

d. Compute Application Rate
Nitrogen Required - Nitrogen Available = Nitrogen to be applied
240 lb/acre - 54 lb/acre = 186 lb/acre
Tons sludge required: 186 lb/acre ÷ 46 lb/ton = 4 tons/acre

Step 2 Check Metals Accumulation

The maximum tolerable heavy metals accumulations depend on the soil cation exchange capacity (CEC). These maximums are shown on Table A-4. These are valid as long as the soil pH is maintained greater than 6.5. At lower pH values the metals are taken up by the crops, resulting in plant damage or possible injury to crop consumers. The metals concentrations are cumulative so previous additions must be considered. Table A-5 shows heavy metal concentrations assumed for this example.

TABLE A-4. TOTAL AMOUNT OF SLUDGE METALS ALLOWED ON AGRICULTURE LAND

Metal	Soil cation exchange capacity (Meq/100 g)		
	0-5	5-15	15
	Maximum amount of metal (lb/acre)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

Determined by the pH 7 ammonium acetate procedure

Table A-5. EXAMPLE HEAVY METAL CONCENTRATIONS

Metal	Concentration ppm	lb/ton
Pb	500	1.0
Zn	750	1.5
Cu	1,000	2.0
Ni	500	1.0
Cd	75	0.15

The cumulative metal additions are shown on Table A-6.

TABLE A-6. METALS ADDITIONS (lb/acre)

Metal	Year 1	Year 2	Year 3	This Year	Total
Pb	10[1](1.0)[2]	10(1.0)	10(1.0)	4(1.0)	34
Zn	10(1.5)	10(1.5)	10(1.5)	4(1.5)	51
Cu	10(2.0)	10(2.)	10(2.0	4(2.0)	68
Ni	10(1.0)	10(1.0)	10(1.0)	4(1.0)	34
Cd	10(0.15)	10(0.15)	10(0.15	4(0.15)	5.1

[1] tons/acre of dry sludge

[2] lb/ton of dry sludge

The totals in the last column of Table 6 are then compared with the values in Table 4. For this example the tons/acre application rate results in a cadmium total addition greater than 5 lb/ac. If the cation exchange capacity is less than 5 meq/100 grams, the safe cadmium level has been exceeded. The application rate would then be lowered for this year and no futher application allowed in subsequent years. The allowable cadmium concentration is 5 lb/acre. Previous applications resulted in 4.5 lb/acre. The allowable application rate is determined as follows: $\frac{5 \text{ lb/ac} - 4.5 \text{ lb/ac}}{.15 \text{ lb/ton}} = 3.33$ tons/acre

The nitrogen balance would be recalculated and supplemental nitrogen added or a decreased yield accepted.

For this example assume the CEC is greater than 5 so sludge application can continue.

Step 3 Determine Supplemental Nutrient Requirements

Phosphorus and potassium balances are checked. For this example, assume a phosphorus content of 40 lb/ton and a potassium for corn growth are 44 and 199 lb/ac/yr, respectively. At 10 tons/acre for three years, the phosphorus addition has been 1,200 lb/ac with only 132 lb/ac being utilized. Therefore, no additional phosphorus is required.

Potassium additions have been 100 lb/ac/yr at the 10 ton/ac application rate, while crop requirements have been 199 lb/ac/yr. At the 4 ton/ac application rate, the potassium added is 40 lb/ac. Therefore, 159 lb/ac supplemental potassium (or potash) is required.

Step 4 Determine Wet Application Rate

All calculations above were based on a sludge dry weight. The operator will be applying sludge with varying concentrations of water. For subsurface injection or spray systems, the liquid sludge will generally be less than 10 percent solids. The dry weight used above of 4 tons/acre is 40 wet tons/ac or 9,592 gal/ac.

Assuming a spreading width of 9 feet and an application flow of 800 gpm, the necessary application vehicle speed is calculated as follows:

$$\frac{9{,}592 \text{ gal/ac} \times 9 \text{ feet}}{43{,}560 \text{ sq ft/ac}} = 1.98 \text{ gal/ft}$$

$$\frac{800 \text{ gpm} \times 60 \text{ min/hr}}{1.98 \text{ gal/ft} \times 5{,}280 \text{ ft/mile}} = 4.59 \text{ mph}$$

or developing a conversion factor for this equipment, the speed is computed as follows:

$$\frac{800 \times 60 \times 43{,}560}{9 \times 5{,}280} = 44{,}000 \text{ (conversion factor)}$$

$$\frac{1}{9{,}592} \times (44{,}000) = 4.59 \text{ mpg}$$

Once the equipment has been selected, the appropriate conversion factor can be computed by the approach shown above.

SUMMARY

Essentially, as shown by the preceding example, the correct sludge application rate depends on the constituent concentration of the sludge and the composition of the soil receiving the sludge. A sludge application rate may be safe at one site but hazardous at another site. The preceding information was developed for agricultural purposes only. Local health officials and regulatory agencies should be contacted for pretreatment requirements and application technique restraints.

APPENDIX B

LANDFILL DESIGN

SLUDGE-ONLY LANDFILL AT A PRESELECTED SITE

TREATMENT PLANT CHARACTERISTICS

- Service Population = 150,000.
- Average Flow = 15 mgd.
- Liquid processes include preliminary screening and grit removal and primary treatment followed by activated sludge, secondary sedimentation and chlorination.
- Solids processes include gravity thickening, mixing, anaerobic digestion, and vacuum filtration.

SLUDGE CHARACTERISTICS

- Solids content is 20 percent.
- Quantity on a dry weight basis = 10 ton/day.
- Quantity on a wet weight basis = 50 ton/day.
- Density = 1700 lb/cu yd
- Quantity on a wet volume basis =

$$\frac{50 \text{ ton/day} \times 2000 \text{ lb/ton}}{1700 \text{ lb/cu yd}} = 58.8 \text{ cu yd/day}$$

CLIMATE FACTORS

- Precipitation = 30 in/yr
- Evaporation = 25 in/yr
- Number of days min temperature freezing or below = 55 days
- Precipitation exceeds evaporation by 5 in/yr

SITE

- Size of property = 280 ac.
- Uniform slope of approximately 5 percent.
- Site currently covered with native grasses.

- No surface water on site.

- Groundwater at a depth of 12 ft; soil moderate to slow permeability.

EVALUATION

- From the characteristics listed in Table 12, the narrow trench method is suitable.

- From the design criteria listed in Table 13, the trench width should be 2-3 ft and the final cover 3-4 ft. There is no bulking agent required and no important soil. The application rate should be 1,200 to 5,600 cu yd/acre.

DESIGN FEATURES

- Excavation - allow 4 ft separation between trench bottom and groundwater; therefore, excavation will be 8 ft.

- Spacing - for stable soil, allow 1 ft for each foot of depth; therefore, spacing between trenches will be 8 ft.

- Width - trench width should be 2 ft (dug with backhoe).

- Length - trench length to prevent solids flow to one end of trench is 200 ft; 5 ft should be provided between trenches for containment.

- Orientation - trenches should be parallel to each other.

- Fill depth - because of the depth of the trench, sludge should not be filled closer than 1.5 ft to top of trench; therefore, depth is 6.5 ft and the usual range is 1 to 2 ft.

- Cover thickness - cover should be 3 ft because of the depth of fill; the usual range is 2 to 3 ft.

SITE DEVELOPMENT

- The site should be divided into fill areas depending on the shape of the area. A wet weather fill area near the entrance to the site should be provided with a paved access road. Adequate buffer around the site would include trees and a chain link fence. Access to the fill areas should be gravel roads leading from the paved wet weather access road. About 50 percent of the site is actually usable fill area.

TRENCH UTILIZATION RATE

- Trench Utilization Rate $= \dfrac{\text{sludge volume/day}}{\text{cross-sectional area of sludge in trench}}$

$$= \frac{58.8 \text{ cu yd/day} \times 27 \text{ cu ft/cu yd}}{6.5 \text{ ft} \times 2 \text{ ft}} = 122 \text{ ft/day}$$

- Sludge Application Rate

$$\text{sludge application rate} = \frac{\text{cross-section area of sludge in trench}}{\text{width of trench + spacing}}$$

$$= \frac{6.5\ \text{ft} \times 25}{2\ \text{ft} + 8\ \text{ft}} = \frac{13\ \text{sq ft}}{10\ \text{ft}} \text{ or } \frac{13\ \text{cu ft}}{10\ \text{sq ft}}$$

$$= \frac{13\ \text{cu ft} \times 1\ \text{cu yd}/27\ \text{cu ft}}{10\ \text{sq ft} \times 1\ \text{ac}/43{,}560\ \text{sq ft}} = 2097\ \text{cu yd/ac}$$

- Land Utilization Rate

$$\text{land utilization rate} = \frac{\text{sludge volume/day}}{\text{sludge application rate}}$$

$$= \frac{58.8\ \text{cu yd/day}}{22097\ \text{cu yd/ac}} = 0.028\ \text{ac/day}$$

- Site Life

$$\text{site life} = \frac{\text{usable fill area}}{\text{land utilization rate}}$$

$$= \frac{.5 \times 280\ \text{acres}}{0.028\ \text{ac/day}} = \frac{5000\ \text{days}}{365\ \text{days/yr}} = 13.7\ \text{yr}$$

APPENDIX C

EXAMPLE COMBUSTION MASS AND ENERGY BALANCE CALCULATION

This example is based on a methodology presented in a paper in the Proceedings of the American Society of Civil Engineers, Journal of the Sanitary Engineering Division, by Mark B. Owen entitled "Sludge Incineration". (10)

This example is for a multiple hearth furnace with no energy recovery.

Sludge Feed

2500 lb/day liquid sludge
80% moisture content
60% of solids are combustible
Chemical analysis of combustible solids:
C - 59.8%, H - 8.5%, O - 27.5%
N - 4.2%, S - negligible

Heat Content of Combustible Solids

$$Q = 14{,}600C + 62{,}000\left(H = \frac{O}{8}\right)$$

Q = heat value, Btu/lb
C = fraction of carbon in fuel (sludge)
H = fraction of hydrogen in fuel
O = fraction of oxygen in fuel

$$Q = 14{,}600\ (0.598) + 62{,}000\left(0.085 - \frac{0.275}{8}\right)$$
$$= 11{,}870 \text{ Btu/lb}$$

Note: Use actual calorimeter test results whenever possible.

Auxiliary Fuel

Fuel oil with a chemical analysis:
C - 85%, H - 12%, S - 1.5%, Ash - 1.5%
Heat content: 148,000 Btu/gal or 19,000 Btu/lb

Specific Heats

CO_2	0.244 Btu/lb/F°
H_2O (vapor)	0.472 Btu/lb/F°
H_2O (liquid)	1.00 Btu/lb/F°
N_2	0.256 Btu/lb/F°
SO_2	0.174 Btu/lb/F°
Air	0.250 Btu/lb/F°
Ash	0.20 Btu/lb/F°

Latent Heat of Water Vaporization (1 atm, 212°F)

970 Btu/lb

Incinerator Operating Conditions

Inlet temperature of all inputs - 60°F
Outlet temperature of stack gas - 900°F
Outlet temperature of ash - 700°F
Excess air - 50%

Dry Solids in Sludge

$$\begin{aligned} M(\text{sludge solids}) &= 2500\ \text{lb/day}\ (1-0.80) \\ &= 500\ \text{lb/day} \end{aligned}$$

Moisture in Sludge

$$\begin{aligned} M(\text{sludge moisture}) &= 2500\ \text{lb/day}\ (0.80) \\ &= 2000\ \text{lb/day} \end{aligned}$$

Combustibles in Sludge

$$\begin{aligned} M(\text{sludge combustibles}) &= 500\ \text{lb/day}\ (0.60) \\ &= 300\ \text{lb/day} \end{aligned}$$

Ash Generated by Sludge

$$\begin{aligned} M(\text{sludge ash}) &= 500\ \text{lb/day}\ (1-0.60) \\ &= 200\ \text{lb/day} \end{aligned}$$

Sludge Heat of Combustion

$$\begin{aligned} H(\text{sludge}) &= 300\ \text{lb/day}\ (11{,}870\ \text{Btu/lb}) \\ &= 3{,}561{,}000\ \text{Btu/day} \end{aligned}$$

Sludge Combustion Reactions

$$\begin{aligned} C + O_2 &= CO_2 \\ 2H + O_2 &= 2H_2O \\ 2N &= N_2 \\ M(\text{C in sludge}) &= 300\ \text{lb/day}\ (0.598) \\ &= 179\ \text{lb/day} \\ M(\text{H in sludge}) &= 300\ \text{lb/day}\ (0.085) \\ &= 25.5\ \text{lb/day} \\ M(\text{O in sludge}) &= 300\ \text{lb/day}\ (0.275) \\ &= 82.5\ \text{lb/day} \\ M(\text{N in sludge}) &= 300\ \text{lb/day}\ (0.042) \\ &= 12.6\ \text{lb/day} \\ M(CO_2\ \text{produced}) &= 179\ \text{lb/day}\ \frac{(44\ \text{mol. wt.}\ CO_2)}{(12\ \text{mol. wt.}\ C\ \ )} \\ &= 658\ \text{lb/day} \\ M(H_2O\ \text{produced}) &= 25.5\ \text{lb/day}\ \frac{(18\ \text{mol. wt.}\ H_2O)}{(\ 2\ \text{mol. wt.}\ H_2\ )} \\ &= 229.5\ \text{lb/day} \\ M(N_2\ \text{produced}) &= 12.6\ \text{lb/day} \\ M(O_2\ \text{required}) &= 179\ \text{lb/day}\ \left(\frac{32\ \text{mol. wt.}\ O_2}{12\ \text{mol. wt.}\ C}\right) + 25.5\ \text{lb/day}\ \left(\frac{32\ \text{mol. wt.}\ O_2}{2(2\ \text{mol. wt.}\ H_2)}\right) \\ &\quad - 82.5\ \text{lb/day} \\ &= 599\ \text{lb/day} \end{aligned}$$

Air Requirements (w/o auxiliary fuel)

$$\begin{aligned} M(\text{combustion air}) &= \frac{599\ \text{lb/day}\ O_2}{0.23} \\ &= 2604\ \text{lb/day} \\ M(\text{excess air}) &= 2604\ \text{lb/day}\ (0.50\ \text{excess}) \\ &= 1302\ \text{lb/day} \end{aligned}$$

Air Requirements (w/o auxiliary fuel) cont.

M(air supplied) = 2604 lb/day + 1302 lb/day
= 3906 lb/day
M(N_2 in combustion air) = (2604 lb/day - 599 lb/day)
= 2005 lb/day

Moisture in Outlet

M(H_2O in outlet) = 2000 lb/day + 230 lb/day
= 2230 lb/day

Latent and Sensible Heat of Free Moisture

H(Free H_2O) = 2000 lb/day ((212°F - 60°F) (1.0 Btu/lb/F°) + (970 Btu/lb)
+ (900°F - 212°F) (0.472 Btu/lb/F°))
= 2,893,500 Btu/day

Latent and Sensible Heat of Combustion Products of Sludge

H(H_2O produced) = 230 lb/day ((212°F - 60°F) (1.0 Btu/lb/F°) + 970 Btu/lb
+ (900°F - 212°F) (0.472 Btu/lb/F°))
= 332,700 Btu/day
H(CO_2 produced) = 658 lb/day (0.244 Btu/lb/F°) (900°F - 60°F)
= 134,900 Btu/day
H(N_2 produced) = 12.6 lb/day (0.256 Btu/lb/F°) (900°F - 60°F)
= 2,700 Btu/day
H(sludge combustion products) = 69,400

Sensible Heat of Excess Air and Nitrogen

H(excess air) = 1302 lb/day (900°F - 60°F)(0.250 Btu/lb/F°)
= 273,400 Btu/day
H(N_2 in combustion air) = 2005 lb/day (900°F - 60°F)(0.256 Btu/lb/F°)
= 431,200 Btu/day

Sensible Heat of Ash

H(Ash) = 200 lb/day (700°F - 60°F)(0.200 Btu/lb/F°)
= 25,600 Btu/day

Radiation and Conduction

Determination of Radiation and Conduction losses requires a detailed analysis of the actual construction and installation of the proposed incinerator. For the purpose of this example the losses are assumed to be 2% of the total heat evolved from combustion processes.
H(radiation and conduction) = 3,561,000 Btu/day (0.02)
= 71,200 Btu/day

Sensible Heat of Shaft Cooling Air

Determination of shaft cooling air sensible heat and the heat available from recycle of cooling air required a detailed analysis of the actual construction and installation of the propsoed incinerator. For the purposes of this example, it is assumed that 10% of the heat evolved from combustion is lost to shaft cooling air and that 90% of this loss is recoverable by recycling the shaft cooling air to the process.

H(cooling air) = 3,561,000 Btu/day (0.10)
= 356,000 Btu/day
H(recycle) = 356,100 Btu/day (0.90)
= 320,500

Mass Balance (w/o auxiliary fuel)

	lb/day
Inputs	
Dry solids in sludge	500
Moisture in sludge	2000
Air	3906
Auxiliary Fuel	-
Total Inputs	6406
Outputs	
Ash	200
Water	2230
Carbon Dioxide	658
Sulfur Dioxide	-
Nitrogen	2018
Excess Air	1302
Total Outputs	6408

Latent and Sensible Heat of Combustion Products of Fuel (per lb of fuel)

h(H_2O produced) = 1.08 lb ((212°F - 60°F)(Btu/lb/F°)
+ 970 Btu/lb + (900°F - 212°F)(0.472 Btu/lb/F°)
= 1560 Btu
h(CO_2 produced) = 3.12 lb (900°F - 60°F)(0.744 Btu/lb/F°)
= 639 Btu
h(SO_2 produced) = 0.030 lb (900°F - 60°F)(0.174 Btu/lb/F°)
= 4.38 Btu
h(final combustion product) = 1560 Btu + 639 Btu + 4.38 Btu
= 2203 Btu

Sensible Heat of Excess Air and Nitrogen (per lb of fuel)

h(excess air) = 7.0 lb (900 F°- 60°F)(0.250 Btu/lb/F°)
= 1470 Btu
h(nitrogen in excess air) = 10.7 lb (900°F - 60°F)(0.256 Btu/lb/F°)
= 2340

Sensible Heat of Ash (per lb of fuel)

h(Ash) = 0.015 lb (900 F°- 60°F)(0.20 Btu/lb/F°)
= 2.52 Btu

Radiation and Conduction (per lb of fuel)

h(radiation and conduction) = (19,000 Btu)(0.02)
= 380 Btu

Sensible Heat of Shaft Cooling Air (per lb of fuel)

h(cooling air = (19,000 Btu)(0.10)
= 1900 Btu
h(recycle) = 1900 Btu (0.90)
= 1710 Btu

Auxiliary Fuel Heat Available for Sludge Incineration (per lb of fuel)

h(available) = 19,000 Btu - 1560 Btu - 639 Btu - 4.38 Btu - 1470 Btu
- 2340 Btu - 2.52 Btu - 380 Btu - 1900 Btu + 1710 Btu
= 12,400 Btu/lb

The mass balance agrees within the accuracy of the assumptions.

Energy Balance (w/o auxiliary fuel)

Inputs	Btu/day
Solids Heat of Combustion	3,561,000
Auxiliary Fuel Heat of Combustion	-
Shaft Cooling Air Recycle	320,500
Total Inputs	3,881,500
Outputs	
Latent and Sensible Heat of Free Moisture	2,893,500
Latent and Sensible Heat of Sludge Combustion Products	469,400
Latent and Sensible Heat of Auxiliary Fuel Combustion Products	-
Sensible Heat of Excess Air	273,400
Sensible Heat of Nitrogen in Combustion Air	431,200
Sensible Heat of Ash	25,600
Radiation and Conduction	71,200
Sensible Heat of Shaft Cooling Air	356,100
Total Outputs	4,520,400

The outputs exceed the inputs by 638,900 Btu/day. In order to maintain the operating conditions specified for the incinerator auxiliary fuel will be required. Had the inputs exceeded the outputs, it would have indicated higher operating temperatures than specified. In order to balance the energy balance equations, new higher outlet temperatures would have to be specified and the energy balance recalculated.

Since in our example, auxiliary fuel is required to maintain the specified conditions, the mass and energy balance must be recalculated to take into consideration the effects of the auxiliary fuel added.

Ash Produced by Fuel (per lb of fuel)

m(Ash) = 0.015 lb

Fuel Combustion Reactions (per lb of fuel)

$C + O_2 = CO_2$

$2H_2 + O_2 = 2H_2O$

$S + O_2 = SO_2$

m(C in fuel) = 0.850 lb

m(H in fuel) = 0.120 lb

m(S in fuel) = 0.015 lb

$$m(CO_2 \text{ produced}) = 0.850 \text{ lb} \frac{(44 \text{ mol. wt. } CO_2)}{(12 \text{ mol. wt. } H_2)}$$

$$= 3.12 \text{ lb}$$

$$m(H_2O \text{ produced}) = 0.120 \frac{(18 \text{ mol. wt. } H_2O)}{(2 \text{ mol. wt. } H_2)}$$

$$= 1.08 \text{ lb}$$

$$m(SO_2 \text{ produced}) = 0.015 \frac{(64 \text{ mol. wt. } SO_2)}{(32 \text{ mol. wt. } S)}$$

$$= 0.030 \text{ lb}$$

$$m(O_2 \text{ produced}) = 0.850 \text{ lb} \frac{(32 \text{ mol. wt. } O_2)}{(12 \text{ mol. wt. } C)} + 0.120 \text{ lb} \frac{(32 \text{ mol. wt. } O_2)}{2(2 \text{ mol. wt. } H_2)}$$

$$+ 0.015 \text{ lb} \frac{(32 \text{ mol. wt. } O_2)}{(32 \text{ mol. wt. } S)}$$

$$= 3.24 \text{ lb}$$

Air Required by Auxiliary Fuel (per lb of fuel)

$$m(\text{combustion air}) = \frac{3.24 \text{ lb } O_2}{0.23}$$

$$= 14.1 \text{ lb}$$

m(excess air) = (14.1 lb)(0.50 excess)
= 7.0 lb

m(air required) = 14.1 lb + 7.0 lb
= 21.1 lb

m(N_2 in combustion air) = 14.1 lb - 3.24 lb
= 10.9 lb

Auxiliary Fuel Required

$$M(\text{fuel}) = \frac{638{,}900 \text{ Btu/day}}{12{,}400 \text{ Btu/lb}}$$

$$= 52 \text{ lb/day}$$

The mass and energy balances are rewritten adjusting the figures for the addition of 52 lb/day of auxiliary fuel.

Mass Balance (final)

Inputs	lb/day
Dry solids in sludge	500
Moisture in sludge	2000
Air	5003
Auxiliary Fuel	52
Total Inputs	7555

Mass Balance (final) cont.

Outputs	lb/day
Ash	201
Water	2286
Carbon Dioxide	820
Sulfur Dioxide	2
Nitrogen	2585
Excess Air	1666
Total Ouputs	7560

This agrees within the accuracy of the assumptions made.

Energy Balance (final)

	Btu/day
Inputs	
Solids Heat of Combustion	3,561,000
Auxiliary Fuel Heat of Combustion (Total)	988,000
Shaft Cooling Air Recycle	409,400
Total Inputs	4,958,400
Outputs	
Latent and Sensible Heat of Free Moisture	2,893,000
Latent and Sensible Heat of Sludge Combustion Products	469,400
Latent and Sensible Heat of Auxiliary Fuel Combustion Products	114,600
Sensible Heat of Excess Air	349,800
Sensible Heat of Nitrogen in Combustion Air	552,900
Sensible Heat of Ash	25,700
Radiation and Conduction	91,000
Sensible Heat of Shaft Cooling Air	455,000
Total Outputs	4,951,900

This agrees within the accuracy of the assumptions made.